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ORIGINAL ARTICLES.

Larger Foraminifera from the Tertiary of Somaliland.

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(PLATES I–IV.)

Introduction.

I. Summary of Stratigraphical Results.

II. Descriptive Palaeontology.

III. Faunal Assemblages and Localities.

Explanation of Plates.

THE foraminifera here described were collected by C. Barrington Brown in the course of a survey as geological member of the Anglo-Italian Boundary Commission of Somaliland in 1929–30. We are indebted to him for the opportunity of investigating these specimens and for the use of his unpublished maps and field-reports.

I. Summary of Stratigraphical Results.

The few publications on the foraminifera of Somaliland are referred to in Section II. The fauna here discussed is of value in determining the age of the beds; and the known geographical range of several of the species is extended. The Miocene is identified by the presence of *Miogypsina irregularis*, associated with small *Lepidocyclina*. The Oligocene is recognized by the reticulate *Nummulites intermedius*. The Middle Eocene is identified by a rich assemblage of forms, which include three species of *Nummulites*. One is referred to *N. discorbinus* var. *major*, originally described from the Eocene of Oman; the other two are new, but are related to Middle Eocene species. The fauna also includes two species of *Dictyoconoides* which occur in the Eocene of India; and *Dictyoconus aegyptiensis*, a species characteristic of the Middle Eocene of Egypt. Finally, there is a new species of the little known genus *Linderina*. The foraminiferal fauna of the beds which underlie this Middle Eocene horizon is meagre. *Siderolites miscella* indicates a Lower Eocene age. *Dictyoconoides tipperi*, *D. newboldi*, *Alveolina subpyrenaica*, and *Flosculina globosa* strongly suggest a Lower Eocene age; only the last two, however, occur in association.

II. Descriptive Palaeontology.

The localities and associated forms are tabulated below in Section III.

A. MIOCENE SPECIES.

Genus Miogypsina Sacco.

Miogypsina irregularis (Michelotti).

Pl. I, Figs. 1–4.

1841. *Nummulites irregularis* Michelotti, *Mem. Soc. Ital. Sci. Modena*, vol. xxii, p. 296, pl. iii, fig. 5.
1900. *Miogypsina irregularis* (Michelotti) Schlumberger, *Bull. Soc. Géol. France*, Ser. III, vol. xxviii, p. 328, pl. ii, figs. 1–7, 9, 10; pl. iii, fig. 17.
1925. *Idem*, Newton, *Mon. Geol. Dept. Hunterian Museum, Glasgow*, No. 1, part 3, p. 17, pl. iii, figs. 7–10.
1926. *Idem*, Chapman, *New Zealand Geol. Surv. Pal. Bull.*, No. 11, p. 93, pl. xviii, figs. 5*a*, *b*; pl. xx, figs. 3, 4.

The specimens examined average 3·8 mm. in length and 0·9 mm. in thickness. The nucleoconch in megalospheric forms is of the type characteristic of the species; the chamber near the exterior margin is large and semilunar.

This species occurs in the Aquitanian and Helvetian of Europe. Newton records it from the Aquitanian of Somaliland, associated with *Lepidocyclina verbeeki* and *L. sumatrensis*. R. Douvillé has mentioned its occurrence in Madagascar (*Ann. Soc. R. Zool. Mal. Belg.*, vol. xliv, 1909, p. 136).

B. OLIGOCENE SPECIES.

Genus Nummulites Lamarck.

Nummulites intermedius d'Archiac.

Form B (Pl. I, Figs. 5, 6).

1853. d'Archiac and Haime, *Monographie des Nummulites*, p. 99, pl. iii, figs. 3*a–d*. 4*a–f*.
1910. Scholz, *Zeitschr. Deutsch. Geol. Ges.*, vol. lxii (Monatsber.), p. 374, fig. 1, 2.
1911. Boussac, "Le Nummulitique Alpin," *Mém. pour serv. éxpl. Carte Géol. détail. France*, p. 84, pl. i, figs. 4, 5; pl. iv, figs. 3 *cum syn.*
1925. Nuttall, *Ann. Mag. Nat. Hist.*, Ser. 9, vol. xv, p. 662. pl. xxxvii, fig. 1; pl. xxxviii, figs. 1, 2 *cum syn.*
1929. Vlerk, van der, *Wetensch. Med. van d. Dienst d. Mijnbouw Ned.-Ind.*, No. IX, p. 18, figs. 31*a*, *b*.
1929. Llueca, *Com. de Invest. Pal. y Prehist. Mem.* 36, Ser. Pal. No. 8, p. 205, pl. xiii, figs. 1–5.

The average diameter of the specimens examined is about 10 mm., the maximum 13 mm. The number of whorls varies from 14 to 20, the average being 15. Equatorial sections show the coiling to be somewhat irregular and the chambers generally much more elongate than broad, but varying considerably in length. The septal filaments are typical (Pl. I, Fig. 5).

This well known and widely distributed species is restricted to the Oligocene: it occurs in Europe (Chattian to Lattorfian),

Persia, India, the Far East, North and East Africa. Scholz figures it from (formerly) German East Africa, and Stefanini records it from Somaliland (*Rendiconti, Cl. sci. fis. mat. nat. d. Real. Acc. Naz. dei Lincei*, Ser. VI, vol. i, 1925, p. 186).

Form A = *N. fichteli* Michelotti (Pl. I, Figs. 7, 8).

1841. Michelotti, *Mem. Math. e Fis. Soc. Ital. Sci. Modena*, vol. xxii, Parte Fisica, p. 296, pl. iii, fig. 7.
1910. Scholz, *Zeitsch. Deutsch. Geol. Ges.*, vol. lxii (Monatsb.), p. 376.
1925. Nuttall, *Ann. Mag. Nat. Hist.*, Ser. IX, vol. xv, p. 664, pl. xxxviii, fig. 1 *cum syn.*
1929. Vlerk, van der, *Wetensch. Med. van d. Dienst d. Mijnbouw Ned.-Ind.*, No. IX, p. 18, figs. 9, 30*a–b*.
1929. Llueca, *Com. de Invest. Pal. y Prehist. Mem.* 36, Ser. Pal. No. 8, p. 209, pl. xiii, figs. 6–13.

The average diameter of the specimens examined is 4·5 mm., the maximum 5·2 mm.; the number of whorls is 8 to 9. The nucleoconch may be double or single.

C. EOCENE SPECIES.

Genus NUMMULITES Lamarck.

Nummulites discorbinus var. *major* Rozlozsnik.

Form B (Pl. I, Figs. 9, 10; Pl. II, Fig. 1).

1929. Rozlozsnik, *Geol. Hungarica*, Ser. Pal., fasc. 2, pp. 121, 123, pl. vi, figs. 16, 25.

Description.—Test lenticular, border rounded. Average diameter 11·2 mm.; maximum 14·4 mm. Average thickness 3·9 mm.; maximum 4·8 mm. Average ratio of diameter to thickness 3 : 1. Septal filaments radiate, numerous and fine, somewhat turbulent centrally but only slightly curved on the remainder of the test. Fifteen to twenty whorls in a radius of 5 to 5·7 mm.; coiling very regular. Sutures straight and slightly inclined to the whorl laminae, which are of fairly uniform thickness throughout.

In one quadrant of the			4th	whorl	there are		7–10	septa.
,,	,,	,,	6th	,,	,,	,,	10–13	,,
,,	,,	,,	8th	,,	,,	,,	12–16	,,
,,	,,	,,	10th	,,	,,	,,	15–19	,,
,,	,,	,,	12th	,,	,,	,,	17–25	,,
,,	,,	,,	14th	,,	,,	,,	20–26	,,
,,	,,	,,	16th	,,	,,	,,	24–29	,,
,,	,,	,,	20th	,,	,,	about	32	,,

Remarks.—Rozlozsnik (loc. cit., pp. 118–23) has discussed at length the difficult problem of the differentiation of species of the *N. beaumonti–discorbinus* group. If his interpretations be adopted, then the Somaliland specimens agree most closely with *N. discorbinus* var. *major*, which was originally described from material collected in Oman by Lees (*Quart. Journ. Geol. Soc. London*, vol. lxxxiv, 1928, pp. 609–10), who considers that the horizon is Middle Eocene.

Form A (Pl. II, Figs. 2–4).

1929. Rozlozsnik, *Geol. Hungarica*, Ser. Pal., fasc. 2, p. 124.

Average diameter 4·4 mm., maximum 5·0 mm. Average thickness 2·5 mm., maximum 2·7 mm. Average ratio of diameter to thickness 1·8 : 1. Nucleoconch double. Average number of whorls in a radius of 2 mm., 7.

In one quadrant of the			2nd	whorl	there are	7–10	septa.
,,	,,	,,	4th	,,	,, ,,	10–13	,,
,,	,,	,,	6th	,,	,, ,,	15–16	,,

Externally, specimens are difficult to distinguish from young individuals of Form B.

Nummulites somaliensis sp. nov.

Form B (Pl. II, Figs. 10–14 ; Text-fig. 1).

Description.—Test flattened, lenticular, irregularly undulate towards the periphery ; sometimes with a central, ill-defined, slightly raised boss. Thickness greatest at the centre, decreasing gradually towards the sharp border. Average diameter 23 mm.,

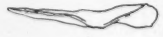

Fig. 1.—*Nummulites somaliensis* sp. nov., Form B. Side-views of Cotype. × 1. (Specimen figured on Pl. II, Fig. 10.) Middle Eocene ; 5 miles at 115° from Hegligab Trig. Station.

maximum 28·5 mm. Thickness varies from 2·2 to 2·8 mm. ; average 2·5 mm. Average ratio of diameter to thickness 9 : 1. Twelve to thirteen whorls in a radius of 11·4 mm. (average) ; towards the periphery the whorls are about 1 mm. apart. Whorl laminae thick, increasing considerably in thickness towards the periphery ; average thickness of laminae of fourth whorl, 0·23 mm. ; average near the periphery, 0·58 mm.[1] Coiling markedly irregular, especially towards the periphery. Size and shape of the chambers varies considerably ; most are longer than broad, but some are broader than long. Sutures always gently curved.

In one quadrant of the			4th	whorl	there are	6–8	septa.
,,	,,	,,	6th	,,	,, ,,	9–11	,,
,,	,,	,,	8th	,,	,, ,,	11–14	,,
,,	,,	,,	10th	,,	,, ,,	15–21	,,
,,	,,	,,	12th	,,	,, ,,	21–25	,,

[1] Since the test is curved, it is impossible to obtain completely equatorial sections ; if the section is *slightly* above or below the equatorial plane, the thickness of the whorl laminae appears less than the true thickness. Accurate measurements of the thickness can be made only in radial section.

Externally the septal filaments appear irregularly turbulent, the pillars being occasionally visible. Tangential sections show that the filaments frequently run parallel for considerable distances, sometimes branching off to, and ending at, a pillar; and occasionally showing an approach to a reticulate structure. The thickness of the filaments is fairly uniform, and pillars are occasionally situated along their length. Towards the periphery the space between the filaments is about 1 mm., and is occupied by numerous circular pillars attaining about 0·1 mm. in diameter.

Remarks.—This species may be considered to belong to the *N. obtusus* Sowerby–*uronensis* Heim group, found in the Lutetian and Auversian. These two species differ by being characteristically much more inflated, more closely coiled, and having septal filaments which are finer with more pillars at the centre than towards the periphery. In shape it resembles most nearly *N. puschi* d'Archiac (d'Archiac and Haime, *Mon. des Nummulites*, 1853, p. 90, pl. i, figs. 5 *a–c*; Boussac, *Mèm. pour expl. Carte Géol. détail. France*, 1911, p. 73).

N. gizehensis Forskal, which has been recorded from Somaliland (Stefanini, op. cit., 1925, p. 186), has a thicker test and is more regularly and closely coiled; its filaments are more uniformly thickened and typically less pilate.

Form A (Pl. II, Figs. 5–9).

Test small, globose-lenticular, with a sharp border. Average diameter 3·7 mm., maximum 4·2 mm. Average thickness 1·5 mm., maximum 1·8 mm. Surface with strong circular pillars and less clearly marked radial filaments. Average diameter of the nucleoconch in equatorial section, 0·5 mm. Average number of whorls in a radius of 1·8 mm., 4. Whorls regular; laminae increasing only slightly in thickness towards the periphery. Chambers longer in a radial direction than broad; sutures gently curved.

In one quadrant of the	1st	whorl	there are	2–2½	septa.	
,, ,, ,,	2nd	,,	,, ,,	3–5	,,	
,, ,, ,,	3rd	,,	,, ,,	5–7	,,	
,, ,, ,,	4th	,,	,, ,,	6–8	,,	

This is considered to be the megalospheric form of *N. somaliensis*, with which it is found associated. It strongly resembles *N. perforatus* Montfort (the megalospheric form of *N. obtusus*), from which it is distinguished by its relative thinness and its acute border.

At Hegligab (Loc. 16) occur in a purple papery shale specimens reaching a diameter of 5·6 mm. which otherwise agree with this form.

Nummulites hormoensis sp. nov.

Form B (Pl. III, Figs. 1–5).

Description.—Test compressed, lenticular with a narrow, slightly wavy border. Average diameter 7·3 mm., maximum 8·0 mm.;

average thickness 2·0 mm., maximum 2·1 mm. Average ratio of thickness to diameter 1 : 3·6. Exterior covered with round tubercles, which form the terminations of internal pillars. Pillars situated above successive whorl laminae. The tubercles are thus arranged concentrically (especially on the peripheral whorls) and mark the position of the whorls on the exterior surface. This last feature is similar to that found in the genus *Assilina*.

Septa straight or gently curved; chambers generally broader than long. Coiling regular. Whorl laminae of medium width, increasing very gradually with the growth of the test. Average number of whorls in a radius of 3 mm., 8.

In one quadrant of the	2nd	whorl there are	4	septa.			
,, ,,	,,	4th	,,	,,	,,	5–6	,,
,, ,,	,,	6th	,,	,,	,,	6	,,
,, ,,	,,	8th	,,	,,	,,	6–7	,,

Septal filaments thickened, meandriform and partly reticulate, large, irregularly rounded pillars occur along their length and less commonly between them.

Remarks.—In external appearance and in the septal filaments this species resembles the Middle Eocene form *N. acutus* Sowerby = *N. douvillei* Vredenburg (Nuttall, *Rec. Geol. Surv. Ind.*, vol. lix, 1926, p. 133). Vredenburg's description (*Rec. Geol. Surv. Ind.*, vol. xxxiv, 1906, p. 79), however, shows that *N. douvillei* has differently shaped chambers, which are longer than broad; also that the number of chambers per whorl is much greater and the specimens of larger diameter.

Form A (Pl. III, Figs. 6–8).

This megalospheric form occurs associated with the above species. The average diameter of the specimens is 3·9 mm.; average thickness 1·5 mm. The external appearance of the test is the same as in *N. hormoensis*. Internally there are six whorls in a radius of 1·5 mm., the nucleoconch being single and about 0·2 mm. in diameter.

In one quadrant of the	2nd	whorl there are	4	septa.			
,, ,,	,,	4th	,,	,,	,,	5–6	,,
,, ,,	,,	6th	,,	,,	,,	6–7	,,

Genus Dictyoconoides Nuttall.

Dictyoconoides kohaticus (Davies).

(Pl. III, Figs. 9–13; Text-figs. 2*a–g*.)

1926. *Conulites kohaticus* Davies, *Rec. Geol. Surv. Ind.*, vol. lix, p. 240, figs. 1–5.
1926. *Conulites kohaticus* var. *spintangiensis* Davies, op. cit., p. 245, fig. 6.
1930. *Dictyoconoides kohaticus* (Davies) van Rijsinge, *Ann. Mag. Nat. Hist.*, Ser. x, vol. v, p. 124, pl. vi, figs. 1–4, text-figs. 1–8.
1930. *Idem*, Davies, *Pal. Indica*, N.S., vol. xv, p. 73, pl. x, fig. 5.

Description.—This species is represented by several hundred specimens, which exhibit the considerable variation in size and shape illustrated in Text-figure 2. The commonest form (Text-figs. 2*d*, *e*) has a slightly convex base with a central rounded depression. Other

specimens have a more strongly convex base, and may have the border turned up, an extreme form being shown in Text-fig. 2*a*. Specimens also occur with a flat and more rarely with a concave base.

The average diameter of twenty typical specimens is 13·0 mm., the maximum observed being 21·3 and the minimum 6·6 mm. The average thickness is 2·4 mm., the maximum being 3·2 and the minimum 1·4 mm. The exterior of the test is identical with Davies' description. The central boss on the dorsal surface is normally surrounded by granulations, which in some specimens coalesce, thus giving the central part of the test a relatively smooth appearance.

In radial sections of the larger specimens, with a radius of 9·3 to 10·5 mm., there are 44 to 49 chambers of the upper layer per radius. In medium-sized specimens (5·4 to 7·0 mm. radius) the number of chambers on a radius is 28 to 32; while in young, incompletely developed specimens (1·0 to 1·2 mm.) the number is 6 to 7. On large weathered specimens, 9 to 10 intercalary whorls are seen on the dorsal surface. In radial sections of specimens with

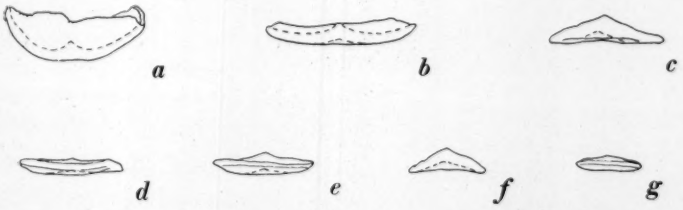

FIG. 2.—*Dictyoconoides kohaticus* (Davies). × 1. Showing variation in shape. Median (radial) section indicated by dotted line. From the Middle Eocene of the following localities: Fig. *a*, Tug Buran, near Buran Pool. Figs. *b*, *c*, 4½ miles N.N.W. of Sunto Trig. Station. Figs. *d–g*, 5 miles at 115° from Hegligab Trig. Station.

a radius of 9·3 to 10·5 mm., the height of the last chamber is 0·4 to 0·5 mm. and the breadth 0·2 mm.

Remarks.—Van Rijsinge (op. cit., p. 130) considers the variety *spintangiensis* synonymous with *kohaticus*; study of the Somaliland material confirms this, every gradation between the species and variety being found. Van Rijsinge also considers that the species included in *Dictyoconoides* would be better referred to the genus *Rotalia* (op. cit., p. 135), since the internal structure of *Dictyoconoides* is essentially that of *Rotalia*. Even if this similarity be admitted, *Dictyoconoides* would represent a highly specialized offshoot from *Rotalia*, with a much more restricted stratigraphical range; and as such is worthy of a separate generic name.

Davies states that in India *D. kohaticus* occurs in the "Kohat Shale, which it peculiarly characterizes", and that the "Kohat Shale would represent an uppermost Ypresian horizon" (1926,

loc. cit., pp. 244–5). The following is a summary of the published occurrences of *D. kohaticus* in India, with the associated foraminifera :—

(*a*) At Kohat, *D. kohaticus* is associated with *Nummulites laevigatus, N. laevigatus* var. *scaber, N. perforatus, N. atacicus, Assilina exponens,* and *A. spira* [Davies, *Journ. Proc. Asiat. Soc. Bengal*, N.S., vol. xx for 1924 (1925), pp. 211, 215–7, 223].

(*b*) At Bahadur Khel, *D. kohaticus* is associated with *N. laevigatus* and *N. perforatus* (op. cit., p. 215).

(*c*) At Harnai, with *N. laevigatus* (op. cit., p. 217).

(*d*) At Chharat, with *N. perforatus, N. laevigatus, N. laevigatus* var. *scaber* and *Assilina spira* (Davies, *Trans. Min. Geol. Inst. Ind.*, vol. xx, 1926, p. 198).

In our opinion, this assemblage of *Nummulites* and *Assilina* would be regarded by all authorities as typical of strata of Lutetian age.

Davies further states that he is uncertain of the age of the rocks at Spintangi from which the type specimens of *D. kohaticus* var. *spintangiensis* were collected : his reasons are not given (*Rec. Geol. Surv. Ind.*, vol. lix, 1926, p. 245). Vredenburg, however, determined the age of the Spintangi section as Lutetian (*Rec. Geol. Surv. Ind.*, vol. xxxiv, 1906, p. 88), recording from these beds the typical Lutetian species *N. perforatus, N. complanatus,* and *Assilina spira.*

D. kohaticus and var. *spintangiensis* are thus associated in India with a typical Middle Eocene fauna, and there seems no justification for the view expressed by Davies that they occur in beds of Lower Eocene age. In Somaliland, as will be seen from the table of occurrences given below, *D. kohaticus* is is associated with Middle Eocene species.

Stefanini has previously recorded *Dictyoconoides* from Somaliland [*Atti d. Soc. d. Nat. e. Mat. di Modena*, ser. VI, vols. v–vi (lvii–lviii fasc. 2, 1927, pp. 84–6].

Dictyoconoides tipperi (Davies).

(Pl. III, Figs. 14–17.)

1926. *Conulites tipperi* Davies, *Rec. Geol. Surv. Ind.*, vol. lix, p. 247, fig. 8.

This species was described from sections only. The illustrations here given of forms from Somaliland help to complete our knowledge of the external appearance of the test.

Average diameter 3·0 mm., maximum 3·2 mm. Average thickness 1·5 mm., maximum 1·8 mm. There are from six to eight whorls of chambers, the last chamber in radial section being on an average 0·2 mm. broad and 0·4 to 0·5 mm. high. On the dorsal surface are numerous rounded tubercles arranged spirally, each tubercle being situated above the junction of a whorl lamina with the upper surface. Very fine canals may be observed running vertically in these granules. Ventrally the surface (except near the periphery) is covered with the irregularly circular, projecting ends of the columns.

D. tipperi may be distinguished externally from young specimens of *D. kohaticus* by its surface ornamentation and its simple spire.

This species has been recorded by Davies from one locality in India; he considers that it would appear to belong to the Laki. Nuttall, who is familiar with the type area, agrees that the beds are of Laki age (Lower Eocene).

Dictyoconoides newboldi (d'Archiac and Haime).

(Pl. IV, Figs. 1–3.)

1853. *Rotalia newboldi* d'Archiac and Haime, *Description des Animaux fossiles du Groupe Nummulitique de l'Inde*, p. 347, pl. xxxvi, figs. 17*a–c*.
1927. *Dictyoconoides newboldi* (d'Archiac and Haime) Davies, *Quart. Journ. Geol. Soc. Lond.*, vol. lxxxiii, p. 279, pl. xxii, figs. 1–4.
1930. *Idem*, Davies, *Pal. Indica*, N.S., vol. xv, p. 74, pl. x, fig. 8.

The specimens from Somaliland appear to be identical with this Indian species. Their average diameter is 1·4 mm., the number of whorls being three to four. On the smooth dorsal surface the spire is visible, while ventrally the lateral chambers are sometimes visible. In the larger specimens there are twelve to fourteen chambers in the last whorl. In the smaller specimens of 1·0 mm. diameter there are about ten chambers; Davies' figure (loc. cit., fig. 4) shows nine chambers of a specimen of the same diameter. These chambers are frequently obscured by the supplementary shell growth covering the central part of the base of the test.

This species was recorded by Davies from the Upper Ranikot (Lower Eocene) of India (op. cit., pp. 264–5). In Somaliland it occurs definitely in the Middle Eocene and in rocks which we regard (with less certainty) as Lower Eocene. No morphological differences were observed between specimens from these two horizons.

Genus Dictyoconus Blanckenhorn.

Dictyoconus aegyptiensis (Chapman).

(Pl. IV, Figs. 4–6.)

1900. *Patellina egyptiensis* Chapman, Geol. Mag., N.S. Dec. IV, Vol. VII, p. 11, Pl. II, Figs. 1–3.
1900. *Dictyoconus egyptiensis* (Chapman) Blanckenhorn, *Zeitschr. Deutsch. Geol. Ges.*, vol. lii, p. 419, 434.
1902. *Conulites aegyptiensis* (Chapman) Chapman, *The Foraminifera . . .*, pp. 135, 156–7, 276 pl. viii, figs. K, k; and fig. 36 (p. 275).
1905. *Dictyoconus egyptiensis* (Chapman) Schlumberger and Douvillé, *Bull. Soc. Géol. France*, ser. IV, vol. v, p. 298, pl. ix.
1925. *D. aegyptiensis*, Silvestri, *Mem. Pont. Acc. Sci. Nuovi Lincei Roma*, ser. II, vol. viii, p. 43, fig. 10.
1926. *Idem*, Silvestri, op. cit., vol. ix, pl. i, figs. 1, 2.
1926. *Idem*, Silvestri, *Riv. Ital. Pal.*, vol. xxxii, p. 18, pl. i, figs. 7, 8.
1927. *Idem*, Silvestri, op. cit., vol. xxxiii, pl. ii, fig. 13.

The average diameter of the specimens examined is about 6·5 mm., the maximum 8 mm.; the average height is about 4·5 mm.,

the maximum 5 mm. In the large number of specimens examined, it was observed that the angle of the cone varies considerably. The base is usually flat or slightly concave, and only in a few specimens is it as convex as in specimens figured from Egypt. The internal structure of forms from the two countries appears to be identical.

According to Blanckenhorn (loc. cit.), *D. aegyptiensis* characterizes the "Untere Mokattam oder Gizehensis-Stufe", which he considers to represent the lower part of the Middle Eocene. *D.* aff. *aegyptiensis* is recorded by Stefanini from Italian Somaliland (loc. cit., 1925, p. 186).

Genus LINDERINA Schlumberger.

Linderina buranensis sp. nov.

(Pl. IV, Figs. 8–14; Text-fig. 3.)

Description.—Test lenticular with a rounded border, the centre in some specimens being raised above the normal convex surface. The microspheric and megalospheric forms can be externally

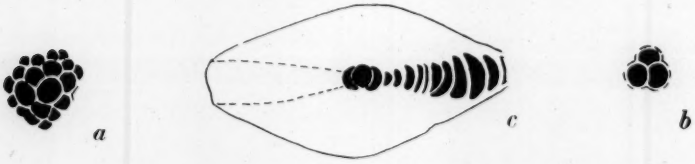

FIG. 3.—*Linderina buranensis* sp. nov. Interpretations of internal structure based on camera lucida drawings. × 30 approx. Fig. *a* equatorial section. Fig. *b* tangential section, passing through three chambers of the nucleoconch; lateral layer surrounding these chambers omitted. Fig. *c* radial section; boundary of median layer on right dotted. Figs. *a*, *b*; 4½ miles N.N.W. of Sunto Trig. Station. Fig. *c*; 5 miles at 115° from Hegligab Trig. Station.

distinguished by their size. The average diameter of the microspheric specimens is 4·1 mm., the thickness 1·3 mm. For the megalospheric forms the same measurements are 2·4 mm. and 1·1 mm. respectively.

The surface of the test is covered with irregularly rounded granules. At the centre these are largest and frequently oval in shape, with the longer axis arranged radially. Towards the periphery the granules are smaller and more circular in outline. They are due to unequal growth at the surface of the shell and are not the terminations of internal pillars as in *Lepidocyclina*.

In radial sections the thick perforate layer is seen on either side of the median chamber layer. In microspheric specimens the median layer is thin at the centre and gradually increases to a maximum of 0·25 mm. in thickness at the border (Pl. IV, Fig. 10). In megalo-

spheric forms, its thickness at the centre is determined by the size of the nucleoconch, the average height of which is 0·2 mm. (Pl. IV, Figs. 11, 12). The septa are arched outwards and have large straight perforations.

In equatorial sections the chambers appear somewhat triangular, the apex pointing to the interior of the shell, and the base being curved (Pl. IV, Fig. 13). The lamina of each whorl is continuous, without the lateral apertures characteristic of *Planorbulina*. Sections not quite on the equatorial plane appear similar to the similarly orientated sections of *L. brugesi* figured by Schlumberger (*Bull. Soc. Géol. France*, ser. III, vol. xxi, 1893, text-fig. 4, p. 121). The only communication from the chambers of the median layer to the exterior is thus through perforations in the septa and in the lateral layer.

In microspheric forms a spiral arrangement of the earliest chambers was observed. In megalospheric specimens it was found difficult to obtain good preparations showing the nucleoconch, which, however, is evidently complex. In equatorial section one larger, central, subcircular chamber is seen, with at least five smaller and compressed chambers around it (Text-fig. 3*a*); but in some sections, not accurately equatorial, three chambers only are visible (Text-fig. 3*b*). In the radial section shown in Text-fig. 3*c*, the large, central, subcircular chamber, with a smaller semilunar chamber on either side, form an oval expansion of the median layer. Normally, however, only two of the larger chambers are seen in radial section (Pl. IV, Figs. 11, 12).

In tangential section (Pl. IV, Fig. 14), are seen the strong perforations at the centre. There are also other darkened portions, which are not pillars of solid shell substance, but parts of the test in which the perforations are extremely minute.

Remarks.—About 200 specimens were examined.

Of the species described under the genus *Linderina*, *L. buranensis* resembles most closely the genotype, *L. brugesi* Schlumberger (*Bull. Soc. Géol. France*, ser. III, vol. xxi, 1893, p. 121, pl. iii, figs. 7–9) from the Eocene of Bruges, Gironde. It has the same typical thick lateral layer, but differs chiefly in its beaded surface and larger size.

The species or specimens which have been referred to this genus are :—

(1) *L.* sp. Newton and Holland, *Ann. Mag. Nat. Hist.*, ser. VII, vol. iii, 1899, p. 262, pl. x, fig. 6. A single radial section from the ? Miocene of Borneo is figured. The generic identification is uncertain.

(2) *L.* ? sp. Newton and Holland, *Journ. Coll. Sci. Imp. Univ. Tokyo*, vol. xvii, art. 6, 1902, p. 15, pl. i, fig. 2. An equatorial section from the Miocene of Formosa. Later Newton (*Mon. Geol. Dept. Hunterian Museum Glasgow*, No. 1, pt. 3, 1925, p. 18) referred this doubtfully to *Miogypsina*.

(3) *L. paronai* Osimo, *Riv. Ital. Pal.*, vol. xiv, 1908, p. 38, pl. i, figs. 13, 14 ; pl. ii, figs. 3–5. From the Eocene of Celebes. The external shape of this species is irregular, and the radial section shows no thick lateral layer.

(4) *L. paronai* Osimo, Provale, *Riv. Ital. Pal.*, xv, 1909, p. 88, pl. ii, figs. 9–12. This form from the Miocene of Borneo strongly resembles *Planorbulina larvata*.

(5) *L. brugesi* Schlumberger, Heron-Allen and Earland, *Journ. Roy. Micro. Soc.*, 1911, p. 332, pl. xii, figs. 1–7. This form was described from shore sand of Selsey, England, and differs very considerably from the genotype.

(6) *L.* sp. Rutten, *Resultats de l'Exped. Sci. néerland. à la Nouvelle Guinée*, 1914, p. 45, pl. viii, fig. 3. From the Miocene of New Guinea. A single radial section figured shows a lateral layer only of moderate thickness.

(7). *L.* sp. Morley Davies, *Report Pal. Zanzibar Protectorate*, 1927, p. 9, pl. i, fig. 11, from the Miocene, is stated to resemble closely No. (1).

Recently Hofker (*Siboga Exped., The Foraminifera*, pt. i, 1927, p. 6) placed the genotype and Nos. 1, 3, 4, and 6 of the list above into the synonomy of *Planorbulina larvata* Parker and Jones. We are in agreement with him in referring the Nos. 3, 4, and 6 to *Planorbulina*, but consider that the genotype *L. brugesi* Schlumberger and the new species here described constitute a distinct genus. Both have a thick perforate lateral layer and are devoid of the lateral openings to the chambers, which produce in *Planorbulina* the characteristic lipped apertures externally at the border.

Douvillé considers that *Linderina* is related to *Siderolites* (*Bull. Soc. Géol. France*, ser. iv, vol. vi, 1906, p. 600). We are, however, in agreement with Hofker (op. cit.) and Cushman (*The Foraminifera, their Classification* . . . 1928, p. 328) in believing that it is related to *Planorbulina*.

Genus Siderolites Lamarck.

Siderolites miscella (d'Archiac and Haime).

(Pl. IV, Fig. 7.)

1853. *Nummulites miscella* d'Archiac and Haime, *Description des Animaux fossiles du Groupe nummulitique de l'Inde*, p. 345, pl. xxxv, fig. 4*a–c*.
1926. *Siderolites miscella* (d'Archiac and Haime) Nuttall, Geol. Mag., Vol. LXIII, p. 116, Pl. X, Figs. 5, 6 ; Text-fig. 3 *cum syn.*
1927. *Idem* Davies, *Quart. Journ. Geol. Soc. London*, vol. lxxiii, p. 277, pl. xx, fig. 9.

This species with its characteristic external ornamentation occurs at one locality in Somaliland. It has previously been recorded from India and Tibet, and is considered as a reliable guide species for the Lower Eocene (Douvillé, *C. R. Séances Soc. Géol. France*, 1928, p. 94).

Genus ALVEOLINA Defrance.

Alveolina subpyrenaica Leymerie.

1844. Leymerie, *Mém. Soc. Géol. France*, Ser. 2, vol. i, p. 359, pl. xiii, figs. 9*a–c*.
1925. Nuttall, *Quart. Journ. Geol. Soc. London*, vol. lxxxi, p. 434, pl. xxiii, figs. 1–3; pl. xxiv, fig. 3.

Typical specimens of this species occurr in a buff-coloured limestone.

Genus FLOSCULINA Stache.

Flosculina globosa (Leymerie).

1844. *Alveolina subpyrenaica* var. *globosa* Leymerie, *Mém. Soc. Géol. France*, ser. II, vol. i, p. 359, pl. xiii, figs. 10*a–c*.
1925. *Flosculina globosa* (Leymerie) Nuttall, *Quart. Journ. Geol. Soc. London*, vol. lxxxi, p. 435, pl. xxiii, figs. 1, 4; pl. xxiv, figs. 4–6.

Specimens of this species occur sparingly in the same limestone sample as *A. subpyrenaica*. The association of these two species in Europe and India has been discussed by Nuttall (op. cit., pp. 429–30), who considers it typical of the Lower Eocene.

III. FAUNAL ASSEMBLAGES AND LOCALITIES.

Of the localities quoted below, some (such as Adad) are to be found (usually with a different spelling) on the map given by Farquharson (*First Report Geol. Miner. Resources Brit. Somaliland*, 1924). Since, however, many of the localities do not appear to be shown on any published map, the approximate longitude and latitude of the key localities (as determined from Barrington Brown's MSS. maps, which are based on the Commission's topographical maps), are here listed :—

	Long. E.	Lat. N.
Barmodobehya	48° 42′	10° 25′
Bunda Ziada Trig. Station	48° 59′	11° 14′ 30″
Buran Pool	48° 47′	10° 13′
Hill 3138′, south-east of Wareigleh	49° 0′ 30″	10° 49′ 30″
Hegligab Trig. Station	49° 1′	10° 21′
Hormo Trig. Station	48° 59′	10° 33′
Madashon Trig. Station	48° 58′	11° 1′
Marojeh Trig. Station	48° 58′ 30″	10° 54′ 30″
Ahangalato (Rhat)	48° 56′	10° 42′
Sunto Trig. Station	49° 1′	10° 39′ 30″

There are several Trig. Stations round Buran : the one referred to here as " Buran Trig. Station " is about ½ mile N.W. of Buran Pool. The present boundary between British and Italian Somaliland in this area follows long. 49° 0′.

A. MIOCENE.

Miogypsina irregularis (Michelotti), a characteristic Miocene form, was collected at :—

Loc. 1. 2 miles at 190° from Bunda Ziada Trig. Station.
„ 2. 2¾ „ 126° „ „ „

At both these localities occur also two species of *Lepidocyclina*, of which there is not sufficient material for identification. At Locality 2 occur also *Ostrea folium* Linné and *Chlamys* (*Aequipecten*) *pallium* (Linné), species which, according to Cox (*Rep. Palaeo. Zanzibar Protectorate*, 1927, p. 48; *Mon. Geol. Dept. Hunterian Museum Glasgow*, No. iv, 1930, p. 109) range from the Miocene to the present day. The age of these beds would thus appear to be Miocene.

B. OLIGOCENE.

Nummulites intermedius d'Archiac (forms A and B) occurs abundantly at:—

Loc. 3. 2 miles at 147° from Bunda Ziada Trig. Station.
,, 4. 3 ,, 138° ,, ,, ,,

The specimens are silicified. Although no other foraminifera were collected at these localities, *N. intermedius* characterizes the Oligocene, and there can be little doubt as to the age of the beds.

C. MIDDLE EOCENE.

Foraminifera were collected at the following localities:—

Loc. 5. 2¼ miles at 145° from Bunda Ziada Trig. Station.
,, 6. 2 miles east of Marojeh Trig. Station.
,, 7. 4½ miles N.N.W. of Sunto Trig. Station.
,, 8. 5 miles at 306° ,, ,, ,, ,,
,, 9. 5 ,, 310° ,, ,, ,, ,,
,, 10. 7 ,, 347° ,, ,, ,, ,,
,, 11. Hormo Trig. Station.
,, 12. 2 miles W.N.W. of Hormo Trig. Station.
,, 13. 3 ,, N.N.E. ,, ,, ,,
,, 14. 6½ ,, N.W. ,, ,, ,,
,, 15. Barmodobehya.
,, 16. Hegligab Trig. Station.
,, 17. 1¼ miles S.E. of Hegligab Trig. Station.
,, 18. 1½ ,, S.W. ,, ,, ,,
,, 19. 3 ,, at 30° from ,, ,, ,,
,, 20. 3¼ ,, 235° ,, ,, ,,
,, 21. 3¼ ,, miles S.S.W. of ,, ,,
,, 22. 3·4 miles at 244° from Hegligab Trig. Station.
,, 23. 4½ ,, 241° ,, ,, ,, ,,
,, 24. 5 ,, 115° ,, ,, ,, ,,
,, 25. 5 ,, 275° ,, ,, ,, ,,
,, 26. Tug Buran, ¼ mile from Buran Pool upstream.
,, 27. Tug Buran, near Buran Pool.
,, 28. 4½ miles at N. 75° E. of Buran Trig. Station.
,, 29. 9 ,, N. 60° E. ,, ,, ,,
,, 30. 13 ,, ,, ,, ,, ,,
,, 31. 2 miles south of Ahangalato (Rhat).

Most of the specimens had weathered out: the matrix is usually a chalky limestone, but at Loc. 16 some of the specimens of *Nummulites discorbinus* var. *major* Rozlozsnik and of *Dictyoconoides kohaticus* (Davies) occur in a purple papery shale.

The occurrences and assemblages may thus be tabulated :—

Loc.	*Nummulites discorbinus* var. *major* Rozlozsnik.		*Nummulites somaliensis* sp. nov.		*Nummulites hormoensis* sp. nov.		*Dictyoconus aegyptiensis* (Chapman)	*Dictyoconoides kohaticus* (Davies)	*Dictyoconoides newboldi* (d'Archiac and Haime).	*Linderina buranensis* sp. nov.	Loc.
	Form B.	Form A.	Form B.	Form A.	Form B.	Form A.					
5							*				5
6	*	*	*	*			*	*			6
7								*		*	7
8	*	*	*	*				*			8
9								*			9
10							*	*		*	10
11	*	*	*	*				*			11
12		*		*			*	*			12
13					*	*	*	*			13
14		*					*	*			14
15	*	*	*	*				*			15
16	*	*						*			16
17	*										17
18			*					*			18
19							*				19
20				*				*			20
21	*	*	*	*			*	*			21
22	*	*	*	*				*			22
23	*	*					*	*			23
24	*	*	*	*				*	*	*	24
25		*						*			25
26							*	*			26
27							*	*	*	*	27
28	*	*		*				*			28
29	*	*		*				*			29
30	*	*	*	*				*			30
31								*			31

This typically Middle Eocene fauna is associated at many localities with a typically Middle Eocene molluscan and echinoid fauna, which will be recorded in a future paper.

D. LOWER EOCENE.

The foraminiferal fauna from these beds is meagre, and their age can therefore not be fixed with so much certainty as the beds already discussed. From field evidence, Barrington Brown informs us that these beds underlie the Middle Eocene beds whose fauna is given above. He recognizes two series, an upper and a lower.

Upper Series.

Dictyoconoides tipperi (Davies) occurs at :—

Loc. 32. Hill 3138′, S.E. of Wareigleh.
,, 33. 3¼ miles at 57° from Marojeh Trig. Station.

At Loc. 32 it is associated with small radiate nummulites, the material being insufficient for determination. As stated above *D. tipperi* occurs in the Lower Eocene of India.

Lower Series.

Alveolina subpyrenaica and *Flosculina globosa* occur commonly in a limestone sample at :—

Loc. 34. Hill 3138′, S.E. of Wareigleh (at a lower altitude than Loc. 32).

Barrington Brown considers that this bed occurs at the top of the Lower Series. The association of these two species is typical of the Lower Eocene.

Dictyoconoides newboldi (d'Archiac and Haime) occurs commonly in massive limestones at :—

Loc. 35. 8 miles west of Hill 3138′, S.E. of Wareigleh.
,, 36. ½ mile S.S.W. of Madashon Trig. Station.
,, 37. ¼ ,, S.W. ,, ,, ,,

No other forms were collected at these localities. The stratigraphical distribution of this species is discussed in Section II.

Siderolites miscella (d'Archiac and Haime) occurs at : Loc. 38 Adad.

This is a definitely Lower Eocene species. From the field evidence, Barrington Brown considers that the rock at this locality is stratigraphically below those at Locs. 35–7.

EXPLANATION OF PLATES I–IV.

Plate I.

Fig.

1–4.—*Miogypsina irregularis* (Michelotti). × 10. Fig. 1, equatorial section, from 2 miles at 190° from Bunda Ziada Trig. Station. Figs. 2, 3, exterior, from 2¾ miles at 126° from the same. Fig. 4, radial section, from same locality as Fig. 1.

5, 6.—*Nummulites intermedius* d'Archiac. × 5. Fig. 5, tangential section. Fig. 6, equatorial section. From 2 miles at 147° from Bunda Ziada Trig. Station. The darker portions are due to the replacement of the test by silica.

7, 8.—*Nummulites fichteli* Michelotti. × 5. Equatorial sections, from 3 miles at 138° from Bunda Ziada Trig. Station.

9, 10.—*Nummulites discorbinus* var. *major* Rozlozsnik, Form B. × 5. Equatorial sections, from 5 miles at 115° from Hegligab Trig. Station.

Plate II.

1.—*Nummulites discorbinus* var. *major* Rozlozsnik, Form B. × 3. Exterior, from 13 miles at N. 60° E. from Buran Trig. Station.

2–4.—*Nummulites discorbinus* var. *major* Rozlozsnik, Form A × 5. Figs 2, 3, equatorial sections ; Fig. 2 from 13 miles at N. 60° E. from Buran Trig. Station ; Fig. 3, 3¼ miles S.S.W. of Hegligab Trig. Station. Fig. 4, exterior, from same locality as Fig. 2.

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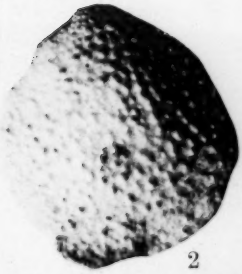
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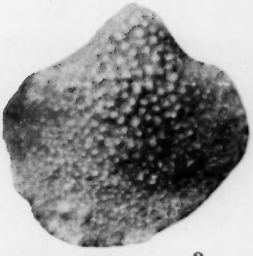
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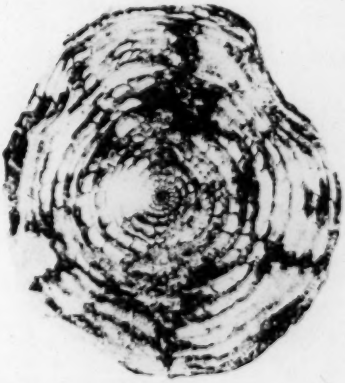
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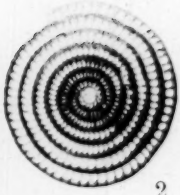
Microphoto by W.L.F.N.

TERTIARY FORAMINIFERA FROM SOMALILAND.

Miogypsina and *Nummulites*.

[*To face p.* 64.

1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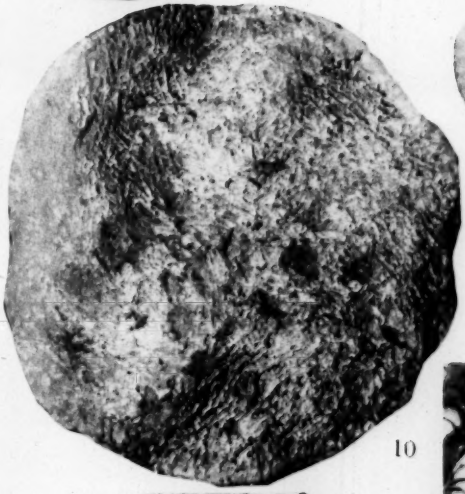
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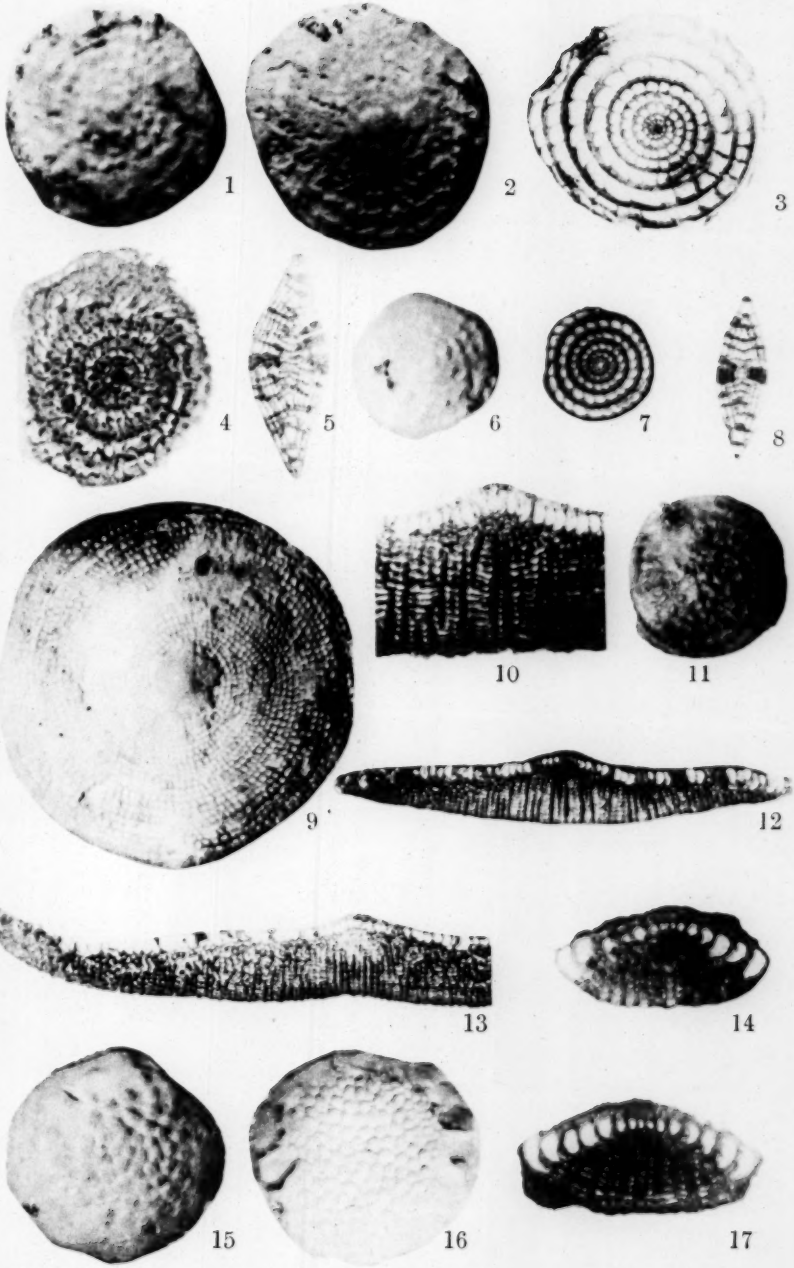
TERTIARY FORAMINIFERA FROM SOMALILAND.

Nummulites.



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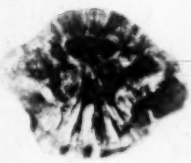
TERTIARY FORAMINIFERA FROM SOMALILAND.

Nummulites and *Dictyoconoides*.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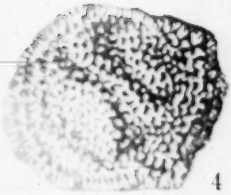
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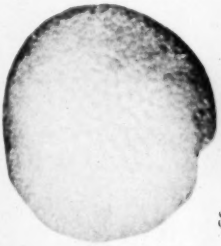
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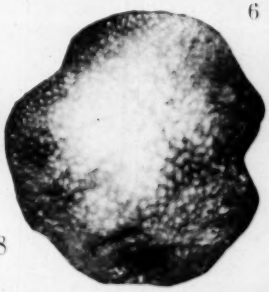
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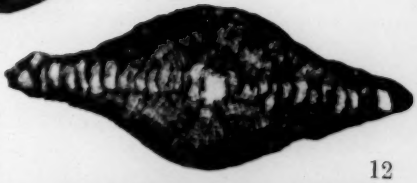
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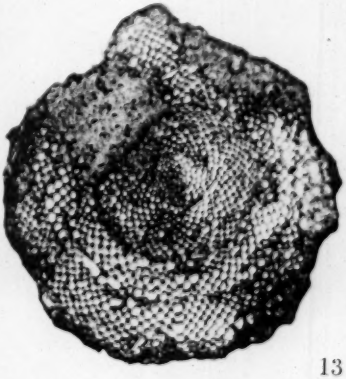
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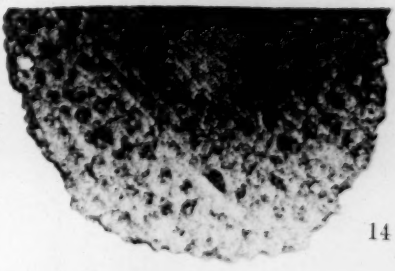
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TERTIARY FORAMINIFERA FROM SOMALILAND.
Dictyoconoides, Dictyoconus, Siderolites, and *Linderina.*

FIG.

5–9.—*Nummulites somaliensis* sp. nov., Form A. × 5. Figs. 5, 6, exterior, from 5 miles at 115° from Hegligab Trig. Station. Fig. 7, radial section, from same locality. Figs. 8, 9, equatorial sections; Fig. 8, from 13 miles at N. 60° E. from Buran Trig. Station; Fig. 9, from same locality as Fig. 5.

10–14.—*Nummulites somaliensis* sp. nov., Form B. × 5. Fig. 10, exterior. Fig. 11, tangential section. Figs. 10, 11, cotypes. Figs. 12, 14, equatorial sections. Fig. 13, radial section. All specimens from 5 miles at 115° from Hegligab Trig. Station.

PLATE III.

1–5.—*Nummulites hormoensis* sp. nov., Form B. × 5. Figs. 1, 2, exterior, cotypes. Fig. 3, equatorial section. Fig. 4, tangential section. Fig. 5, radial section. All from 3 miles N.N.E. from Hormo Trig. Station.

6–8.—*Nummulites hormoensis* sp. nov., Form A. × 5. Fig. 6, exterior. Fig. 7, equatorial section. Fig. 8, radial section. All from same locality as Fig. 1.

9–13.—*Dictyoconoides kohaticus* (Davies). Fig. 9, × 5, dorsal view of specimen with cortical layer removed, from 5 miles at 115° from Hegligab Trig. Station. Fig. 10, × 10, central part of radial section, from Tug Buran, near Buran Pool. Fig. 11, × 10, young specimen, showing intercalary whorls, dorsal view of exterior; from same locality as Fig. 9. Figs. 12, 13, × 5, radial sections, from same locality as fig. 10.

14–17.—*Dictyoconoides tipperi* (Davies). × 10. Figs. 14, 17, radial sections. Figs. 15–16, views of exterior of same specimen; Fig. 15, dorsal surface; Fig. 16, ventral surface. All from 3¼ miles at 57° from Marojeh Trig. Station.

PLATE IV.

1–3.—*Dictyoconoides newboldi* (d'Archiac and Haime). Fig. 1, × 20, radial section. Figs. 2, 3, × 10, views of exterior; Fig. 2, dorsal surface; Fig. 3, ventral surface. All from 5 miles at 115° from Hegligab Trig. Station.

4–6.—*Dictyoconus aegyptiensis* (Chapman). Fig. 4, × 5, tangential section near base. Fig. 5, × 5, exterior with cortical layer removed. Fig. 6, × 10, radial section. All specimens from 3 miles N.N.E. of Hormo Trig. Station.

7.—*Siderolites miscella* (d'Archiac and Haime). × 10, exterior, from Adad.

8–14.—*Linderina buranensis* sp. nov. Figs. 8, 9, × 10, Form B, exterior, cotypes, from 4½ miles N.N.W. of Sunto Trig. Station. Fig. 10, × 10, Form B, radial section, from Tug Buran, near Buran Pool. Fig. 11, × 10, Form A, radial section from same locality as Fig. 8. Fig. 12, × 20, Form A, radial section, from same locality as Fig. 10. Fig. 13, × 10, Form B, equatorial section, from same locality as Fig. 10. Fig. 14, × 20, Form B, tangential section, from same locality as Fig. 8; the striations seen in this section are due to scratches on the preparation.

Some Boulders from the Chalk of Betchworth, Surrey.

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Department of Geology, The University, Liverpool.

THE presence of small quantities of detrital (terrigenous) minerals in the Chalk has been recorded from such widely-separated areas as Northern France (1),[1] the Isle of Wight (2), Antrim (3), Mull (4), and East Anglia (5), but the discoveries of boulders in that formation

[1] Figures in parentheses relate to References at the end of this paper.

appear to be restricted to the south-east of England. These records may be due to the greater extent of the workings in the Chalk of that area, and hence the greater frequency with which these " foreigners " are uncovered, or to some definite geographical conditions prevailing in Cretaceous times. The information available seems to prove that Betchworth has yielded more boulders than all other areas added together. In 1897, W. P. D. Stebbing (6) described two granitic rocks from that area. The present paper deals with a small collection of nineteen boulders made by the late Gerard Weedon Butler, also from Betchworth. Since these notes were first drafted the writer has been informed that a collection of something like 70 boulders, mainly from Betchworth, has been added since 1912 to those that were already in the Museum of Practical Geology.

In the paper referred to above Stebbing (6, p. 213) collected together the information concerning foreign rocks in the Chalk. A short summary may be useful here. As early as 1827 Mantell (7) made a general reference to the presence of quartz and green schist in the Chalk of the south-east of England. In 1850 (8) sandstone and quartz-rock were discovered at Houghton, Sussex, whilst in 1857 (9) the well-known Purley boulder, a syenitic rock, was found associated with sand, gravel and greenstone. In 1860 (10) bituminous coal with ferruginous clay was recorded from a railway tunnel near Dover. Large stones mixed with rotten wood have been discovered at Isleham (11), whilst sundry boulders and fragments of wood from the Sussex Chalk are preserved in the Brighton Museum. A quartzite boulder from West Thurrock, and two, of quartzite and greenstone respectively, from Gayton, Norfolk, are housed in the Museum of Practical Geology.

The boulders that are the subject of the present paper were presented to the Department of Geology of the University of Liverpool by Mr. C. P. Chatwin. They were collected by Gerard Weedon Butler, and their provenance is beyond question.

Butler's original descriptive label reads as follows :—

" Erratic stones *found all near together* in the chalk at Betchworth.

" With the exception of stones 1–3, they are all grits in some cases passing into quartzites. 1–3 are granitic rocks with the felspars decomposed.

" Many of the grits show a marked pitting of the surface corresponding to cavities or loose-grained and often iron-stained spots seen on freshly broken surfaces.

" The Rings and Pointers mark fossil organisms confirming that the stones lay at the bottom of the sea while the chalk was being formed."

The fossils to which Butler draws attention are ill-defined annelids and polyzoa.

Detailed Description of the Boulders.

One of the nineteen specimens is a piece of Chalk showing a partly enclosed fragment of quartzite about three quarters of an inch in length. It is possible that Butler only collected the larger specimens and left similar small ones behind. The other boulders may be roughly classified as fourteen quartzites, two sandstones and two igneous rocks. It appears there were originally three rocks of igneous origin, but No. 2 is not in the collection now. All are well-rounded and smoothed, with no projecting corners or edges, and some have the flattened ovate form exhibited by well-worn beach pebbles. The sizes and weights are somewhat variable, but about half of the specimens are fairly uniform in size and measure about $3\frac{1}{2}$ in. by 3 in. by $1\frac{1}{2}$ in. The two largest are about 7 in. long, 6 in. wide and $2\frac{1}{2}$ in. thick, and the heaviest weighs nearly 5 lbs. The smallest specimen measures $2\frac{1}{2}$ in. by 2 in. by 1 in. One of the igneous rocks has apparently been sawn in two and, as the part remaining measures 3 in. by $3\frac{1}{2}$ in. by 2 in., it may originally have been one of the largest of the boulders.

Igneous Rocks.

The two rocks of igneous origin (Nos. 1 and 3) appear to be slightly decomposed, for the outer crust is somewhat friable and pitted. The pittings lie in nearly parallel planes so that the resulting ridges show the foliation of the rocks. This feature is further seen on a flattened, polished surface in each example where the linear arrangement of the constituents is manifest. Each rock consists essentially of quartz and felspar, with subsidiary amounts of mica and iron oxides, though there is some variation in the secondary constituents. No. 1 consists almost entirely of quartz and felspar. The quartz occurs both as large grains, full of minute inclusions, and also as a granular aggregate of crushed and broken fragments. The larger crystals display slightly undulose extinction. The felspar is mainly a finely cross-hatched microcline, but orthoclase is also present. This again is in part crushed and broken. A brown pleochroic biotite is present in small amount, and is usually in juxtaposition with an iron oxide mineral which is marginally altered to yellowish brown decomposition products.

No. 3 also shows the effects of foliation, with lenticular aggregates of broken minerals and also a development of secondary mica in the crushed areas. A thin section shows rather more quartz than does No. 1, whilst microcline is less prominent and both orthoclase and plagioclase are present. The plagioclase is turbid with decomposition products, though lamellar twinning is still apparent; the refractive index is higher than that of the microcline, but lower than that of the Canada balsam (1·539). Evidently the felspar was an acid plagioclase. Among the secondary products, mica and a pale epidote are identifiable. In this specimen both biotite and muscovite are original constituents and are occasionally intergrown.

Iron oxide is less abundant than in No. 1. One large zoned zircon was noted.

From the above description it will be evident that both rocks are slightly foliated granites.

Stebbing's two boulders of granite from the same place were described by Bonney (6, p. 216), who identified in Boulder A quartz full of minute cavities and often with slight strain-shadowing, felspars, plagioclase, microcline and probably orthoclase, a doubtful pinite (? after cordierite), altered biotite and iron oxide, zircon and (?) rutile. The structure, he said, was not that of a normal granite, but more nearly resembled one of those which are so often banded and commonly occur in a complex of the older Archæan. In Boulder B he identified quartz, plagioclase, orthoclase, a little biotite but more white mica, and impure red garnets. He stated that in this rock there were signs of mechanical action, the mica was bent or "rucked", quartz and felspar cracked and re-cemented, that in short the rock was gneissoid from pressure and resembled those that are rather common in the same regions as the last named (Boulder A). His general conclusions would apply equally well to our specimens No. 1 and No. 3.

Sandstones.

The two specimens of sandstone differ considerably in appearance. No. 4 is rather flat and parallel-sided, and has only suffered sufficient erosion to make the cross-section rectangular with rounded corners, whilst the cross-section of No. 5 is elliptical. Again, No. 4 is of a pale greenish colour throughout, whilst No. 5 is brownish-red and displays colour-banding. Some four bands are distinguishable, the innermost being chocolate coloured. Both boulders consist mainly of quartz.

In No. 4 the average grain-size is about 0·06 mm., and quartz, decomposed felspar, pale biotite and zircon may be identified in a thin slice. A portion of the rock was crushed and the heavier constituents were isolated in bromoform. The heavier fraction contained abundant small zircons about 0·04 mm. in length, a considerable amount of fragmentary garnet, with rare muscovite, reddish rutile and a brown tourmaline. Most of the zircons were of good form and unabraded. The lighter fraction consisted of quartz angular in form and felspar too decomposed to permit of exact determination.

The brownish specimen No. 5 also consists mainly of quartz and felspar. In contrast with No. 4 the relative abundance of the most common heavier constituents is reversed, for though small colourless prisms and pink and purple ovoid grains of zircon are still abundant, nearly half of the residue consists of small colourless fragments of garnet. Mica and rutile are present in minor amounts, with chlorite very rare. The colouring matter is limonitic, with possibly some haematite.

The Quartzites.

These vary in colour from nearly pure white to the liver-coloured type found in the Bunter Pebble Beds. In those specimens which have been sliced the grain-size varies considerably. In one it is fairly uniform, with the individual grains about 0·4 mm. in diameter: in another it is about 0·2 mm., whilst in a third there is more variation, the grains ranging from 0·14 to 0·18 mm. in diameter. In all the specimens there are occasional rounded grains, but the usual form is sub-angular. A few grains show outgrowths of secondary quartz in optical continuity. Rows of minute inclusions of gas or liquid are present, and the extinction is occasionally undulose. Cloudy felspar, fresh microcline, and a rare grain of garnet or zircon complete the mineral assemblage as seen in thin section.

The heavier minerals were isolated from two of the quartzites in the usual way. The heavier fractions were very small. In one, purple zircon, mica, and tourmaline were found, and in the other, one specimen of a fibrous amphibole, ilmenite, anatase (?), tourmaline, rutile and thin flakes of chlorite.

For comparison, Bunter quartzites from the Midland area were examined. In these the grain-size was found to vary between 0·08 mm. and 0·12 mm. The constituents were seen to be quartz, felspars, including microcline, rare mica and, in one specimen, occasional brownish-green tourmaline. The general appearance in thin slice and in residues was quite comparable with that of the specimens here described.

A flaggy bed from the Grès de May of Cavalle Quarry, Caen, was also examined. Here the heavier constituents contrast markedly, for brookite and rutile are relatively common. The rutile is yellow and is polysynthetically twinned. Zircon is abundant, with tourmaline and mica. On mineralogical evidence it does not seem possible that the Chalk quartzite specimens were derived from that formation.

Original Source of the Rocks.

So far as the writer is aware, Butler left no record as to whether these boulders were found altogether at one time, or at different times. They are all derived from one horizon, the Middle Chalk, but whether there was any vertical as well as lateral distribution is uncertain. A vertical distribution through the Chalk might indicate the maintenance of similar conditions, or the recurrence of similar conditions during a considerable period, and so might point to definite palaeogeographical conditions.

The adhering fossil remains show that the boulders lay on the floor of the Chalk Sea for some considerable period before being buried under additional sediment, and that the conditions were comparatively quiet. As only prolonged attrition could reduce blocks of quartzite or, indeed any one of the boulders to its present form, it seems evident that they had acquired their present

form before their deposition at Betchworth and that they must have been derived, as boulders, from an older formation. The general petrological character of the assemblage (sandstones and quartzites with an occasional igneous rock), coupled with the character of the quartzites suggest that they may have been derived from the Bunter Pebble Beds. In the various memoirs describing the coarser varieties of this formation such an assemblage of rocks is commonly noted. The mineral constitution of the specimens, while not very distinctive, favours such a possible derivation.

Any discussion of the means by which the boulders reached the place where they were found can only be speculative. Mineral and chemical analyses show that the Chalk as a whole is a rock of great purity and that terrigenous material is only present in very small quantities. This consideration alone shows that no ordinary active drainage system bearing the usual detritus could have been in operation near to Betchworth at the time; consequently it is necessary to turn to some other unusual method of transport, such as floating trees, sea-weed or occasional icebergs or floes. As there is no evidence for supposing that the margin of the Chalk Sea at the time lay anywhere near Betchworth, the material must have been brought from a considerable distance. Both trees and ice are capable of such transport. The presence of decayed wood in the Chalk at Isleham and of fragments in the Sussex Chalk suggests the possibility that trees were the transporting agent. But boulders such as these could only have been carried by comparatively large tree-like masses of wood; fragments of wood, even if it were possible to imagine any means of attachment, would not suffice. If trees were growing on the outcrop of the parent rock of the boulders, they might, if uprooted into water, have carried off some material entangled in their roots. Once in the water, however, the rounded nature of the boulders would tend to prevent their remaining suspended for any length of time. It would be easier for irregular joint-blocks to be firmly held in roots and so transported for great distances, but no such angular blocks have been recorded. If a tree became water-logged and sank with its load at Betchworth we might expect that some evidence of woody material would remain. However no wood has been so far recorded from Betchworth. It is possible that this locality was just about the limit to which entangled material could be borne, and that the load was there dropped, while the transporting agent floated farther away. Similarly, some of the smaller boulders may have been floated off the Chalk shore by masses of sea-weed of which no evidence remains. In this case, a bouldery beach and long transport must be postulated. There remains the possibility of the boulders having been carried by floating ice, but here again the evidence is by no means satisfactory. The general characters of the rare detrital minerals found in the Chalk, and particularly the fretted surfaces of the rounded quartz-grains, have been regarded

as indicating transport by wind. Professor E. B. Bailey has used the evidence of rounding together with other phenomena, such as local silicification of sandstone, to show that the shores of the Chalk Sea were desert-like. Whilst this would not absolutely preclude ice-transport, it is hardly favourable evidence. Whatever may have been the means of transport (and the writer feels that it must be left an open question) the Betchworth area appears to have received a concentration of these erratics, and this fact, as Hume has suggested, "implies either a local or an oceanic current, and if this be true we have obtained one point along the great water highways of the period".

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A Suggested Interpretation of the Scottish Caledonide Structure.[1]

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I VENTURE to present before the Section a new interpretation of the Scottish Caledonide structure. This essay is based partly on the impressions that I got on a short visit to the Northern Highlands and on a most instructive excursion to Ballachulish under Mr. E. B. Bailey's inspiring guidance; partly on my own experience of the tectonics of Central European crystalline regions; but of course, above all, on the work of many Scottish geologists.

My discussion may start from the three well-known divisions of the crystalline schists in the Scottish Highlands which have been

[1] Paper read before Section C, Geology, British Association, Johannesburg, 1929.

named the *Lewisian*, the *Moinian*, and the *Dalradian*. These divisions are by no means equivalent to each other, and the junction between the first and the second has a tectonic significance quite different from that between the second and the third. The Moine thrust separates the Lewisian from the Moinian. It is famous as the first well recognized large scale example of transportation of more ancient crystalline schists over fossiliferous sedimentary rocks ; and is still more famous through the work of Lapworth, Peach, and Horne—a world standard of careful, thorough investigation and lucid description.

The Lewisian Gneiss is unconformably covered by the enormously thick sequence of the Precambrian Torridon Sandstone. Great masses of crystalline rocks must have been removed before the Torridon Sandstone was spread over the actual surface of the Lewisian Gneiss, of which the metamorphism is consequently of the highest antiquity and has no relation whatever to the early Paleozoic folding of the Caledonian chain. Likewise, the Torridon Sandstone has not suffered any remarkable folding or metamorphism, except in the immediate neighbourhood of the Moine thrust, where it has been affected by the great shearing movement. The whole Lewisian region remains outside of the Caledonian folding zone. It has been considered as its Foreland.

On the other hand, the Moinian and the Dalradian regions are intricately bound together by very complicated folding and thrusting. The boundary between them is most irregular and the distinction is based on the character of their respective type of metamorphism. Evidently the one region has not merely been thrust over the other, as the Moinian is thrust over the Lewisian ; but both regions have been involved as a whole in one and the same extensive and regional tectonic movement.

To the south-east the Dalradian zone is sharply cut off by the Highland boundary fault. South-east of this fault a broad band of the mountain range has subsided, and most of it is now hidden below the cover of Old Red Sandstone and Carboniferous sediments. However, some narrow outcrops of strongly folded fossiliferous Ordovician rocks almost touch the metamorphic Dalradian and, with exposures of Silurian in the Pentland Hills, show that the metamorphic portion of the Caledonian range has come to an end not far from the boundary line.

Considering its visible extent from Durness as far as Shropshire we can observe a division of the Caledonian orogen proper into three clearly defined zones, which are arranged according to the same plan as the zones in the younger and more complete orogens of Middle Europe, in spite of far-reaching individual variations. The first and outer zone, i.e. the zone of non-metamorphic folds, is traceable under its transgressive cover, from Shropshire to the Highland boundary fault. It corresponds in general to the non-metamorphic zone of the Alps, which includes the Helvetian nappes in Switzerland

and their partly visible continuation in the Sandstone—or Flysch—zone of the Eastern Alps. More fully developed and better exposed, in spite of incomplete preservation, is the equivalent in the Horsts of the Variscan-Hercynian mountain belt. This comprises all the non-metamorphic Devonian of the Rheinisches Schiefergebirge, including the Harz and the Thüringer Forest.

The Caledonian middle zone, i.e. the Dalradian, finds its unmistakable counterpart in the Pennide zone of the Central Alps; both of these show the same kind of intense folding and overthrusting and consequently the same type of metamorphism. In the Variscan arc only a relic of a once equally potent middle zone is represented in the nappes of the Erzgebirge, where moreover its general appearance is modified by a greater share of older gneisses and foliated older intrusions incorporated in the pile of nappes.

Still more liable to individual variations are the regions which we have to consider as the third or innermost zones of the orogens. The range of metamorphism may comprise lowest and highest grades according to local conditions; but their rôle in the orogen is marked by the peculiarity that they contain more or less extensive areas of deep, *post-tectonic crystallization* (corresponding to the undermost zone or zone of katametamorphism in the sense of Becke).

This zone is represented in the Variscan arc by the great so-called Moldanubian Block, south of the Erzgebirge; and in the Alps by the so-called East Alpine nappes (Austrides) and the crystalline base of the Dinarides. The contrast to the second or middle zone is most clearly emphasised in the Moldanubian Block, which consists almost entirely of kata-rocks, the metamorphism of which is post-tectonic and produced by the intrusions of enormous granitic batholiths (Intrusion Tectonics, 10 [1]). The Moldanubian Block has been moved as a whole over the nappes of the Erzgebirge and carries on its back the non-metamorphic older Paleozoic of Middle Bohemia, the so-called Barrandien. In my own experience, most of the rocks that are described as mica-schists and phyllites in this region, are in reality products of retrograde metamorphism by more or less extensive local shearing.

What is the meaning of these three zones? The principle that rules their arrangement is most clearly exposed in a third Central European mountain range. The discovery of this range is of comparatively recent date, and hence it has been generally too little considered and its significance in the older European structure has not been duly appreciated. This so-called *Moravo-Silesian range* accompanies the eastern border of the Bohemian massif through its whole length from the Silesian plain near Troppau almost up to the Danube near Krems. It has been dissected and broken by a great number of faults after the close of the folding period.

The name Moravo-Silesian has been given with special reference

[1] Figures in parentheses refer to Bibliography at end of paper.

to the metamorphic folded zone, that is to the middle zone of the orogen (10). The corresponding outer, non-metamorphic zone is represented by considerable remains in the mainly Devonian and Culm hills of Silesia, to the east of Troppau. What we call the third zone is more clearly defined and its tectonic significance is more obvious than in any of the other named orogens. It belongs to the Moldanubian Block of intrusion-tectonics and post-tectonic crystallization. (Fig. 1.)

The boundary between the Moldanubian and the Moravian is an over-thrust plane on the largest scale. A continuous layer of mica-schists, produced from the Moldanubian gneisses by intense shearing below the thrust-plane, is intercalated between them. The boundary, as it has been exposed by erosion, takes a very sinuous course and surrounds large windows of the Moravian. Obviously, the Moldanubian Block has been shifted as a whole, and without any remarkable folding or corrugation, over the Moravian ; and evidently this powerful movement has pushed together the Moravian rocks into a pile of nappes and impressed on them the characteristic features of meso- and epi-metamorphism.

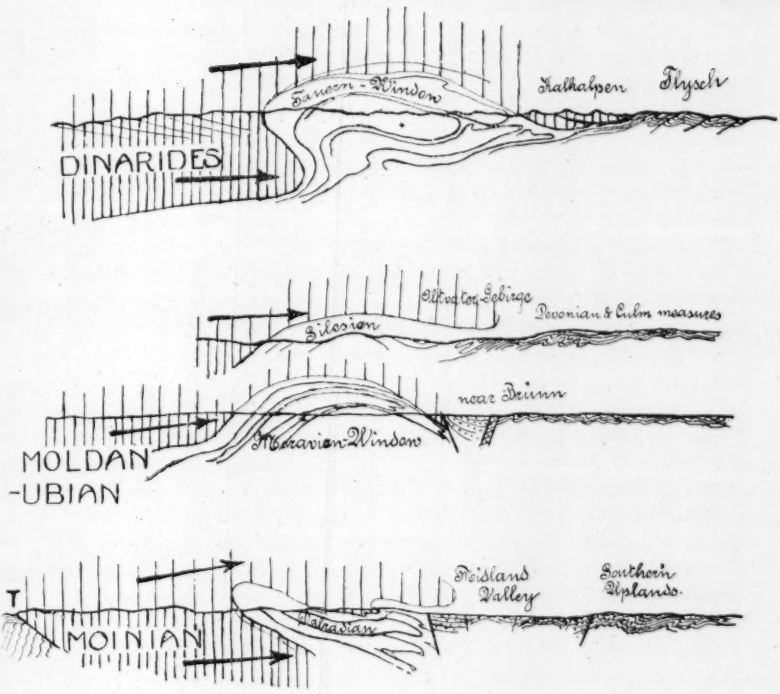
Let us now return to the Scottish mountains. The most conspicuous of the three above-mentioned truly Caledonide zones, the richest in varieties of rocks, the one with the most fascinating and most complicated tectonic features is the *Dalradian*. We owe to Bailey the demonstration of a system of recumbent slides and folds which dominates the south-west part of the Dalradian ; and similar structures have been recognized by Bailey, MacGregor, Anderson, Read, and Elles in the middle and northern parts of the Central Highlands.

Bailey's comparison of this region with the Pennine nappes of Switzerland certainly meets the point and, I think, no other region has hitherto been scientifically described that surpasses these in complication, in the degree of stress and consequently of deformation of the rock masses.

The superposition of several nappes, representing well defined structural divisions, each of which comprises a group of strata in various stages of metamorphism, such as has been demonstrated by Bailey, simulates very closely the sheared series of Grisonide nappes in the West Alpine Bernina district, in which an enormous thrust of the overlying crystalline basement over the East Alpine (Austride) nappes has occurred.

Of course the character of the Scottish nappes is somewhat different from that of the Central Alpine nappes, on account of the difference in their lithological composition, the lesser amount of the calcareous element, the prevalence of arenaceous and quartzose schists, and perhaps also a more thorough and uniformly pervading metamorphism have given to the Dalradian a tendency to produce more homogeneous folds with a more supple flow.

From various studies of Bailey, MacGregor, Anderson, Elles,



T = Moine thrust.

Creative blocks
(prevalent post-tectonic crystallization).

Regions of Pennide type
(prevalent nappe-structure and syntectonic crystallization).

Zone of folded non-metamorphic rocks.

Post-tectonic (transgressive) sediments in the Midland-valley and in the "Boskonitzer-Furche" near Brünn.

Lewisian with overlapping Torridonian.

FIG. 1.—Types of Mountain Structure.

and others, we can take it for granted that in principle the same structural features dominate the Dalradian to the coast of Banffshire, corresponding to the north-eastern trend of the fold-system as a whole.

The principal members of the sequence can be followed through the whole extent of the Dalradian. The question whether the stratigraphical sequence in some tracts may be normal or reversed, complete or incomplete, is not essential to the interpretation of the Dalradian as a region of Pennine type ; i.e. of most complicated sliding and folding.

Further, the tectonic history of any rock is *most definitely expressed in the characters of its metamorphism,* and accordingly many varieties and gradations of metamorphism are met with in the Dalradian corresponding with the intricacy of the tectonic phenomena of the complex.

Space permits but few remarks on this great topic.

As we learn from various descriptions, the range of mineral constituents comprises the characteristic members of the so-called meso- and epizones (in the sense of Becke and Grubenmann).

Cordierite is only found in the contact aureoles of post-tectonic granitic bosses, and is not referable to the conditions under which the Dalradian rocks proper crystallized. Exactly the same holds good in the second zone, the zone of metamorphic folding, in the three Central European mountain ranges already referred to.

The minerals are in different schists of the Dalradian combined in the characteristic crystalline facies, corresponding to the respective conditions of pressure and temperature at the time of crystallization : biotite, sillimanite, kyanite, staurolite, orthoclase, etc., at one end, and chlorite, zoisite, epidote, albite, at the other.

It is obvious from many descriptions of the region that the rocks of different crystalline facies in the Dalradian are by no means arranged according to any supposed vertical order expressing the physical conditions that might have governed their individual origin.

Tilley (11) has recently pointed out the reversed order of the main zones of metamorphism throughout the south-west half of the Dalradian. A south-eastern chlorite-zone dips north-westward below the biotite-zone and this last is overlain by the garnet-zone. Elles has indicated the same sequence in the more complicated Ben Lawers and Meall Corranaich district in Perthshire. As the general trend of these main zones is not parallel to the Boundary Fault, but approaches it more and more to the north-east, the chlorite and biotite-zones gradually become narrower in this direction. In return the sequence is amplified in this region by the addition of sillimanite, kyanite, and staurolite to the index minerals of the metamorphic zones. Moreover there are many more or less local breaks in the succession of the metamorphic rocks, metamorphic unconformities with sharp lines of demarcation ; a fact implying folding subsequent to a first stage of metamorphism.

According to our experience in different crystalline regions of Middle Europe, kyanite and staurolite, as characteristic minerals of mica-schists and micaceous gneisses, belong to the mesozone. I may mention the mica-schists with staurolite at the base of the Austrides that are thrust over the chlorite-schists and phyllites of the Pennide zone on the northern border of the " Window of Tauern " near the Brenner Pass, south-east of Innsbrück.

Putting aside the question to what degree the metamorphism was produced by granitic intrusions before or during the folding, it can be concluded from the descriptions by various authors that metamorphic rocks have been folded and that different facies of metamorphism have been involved in the folding. The metamorphism has been inaugurated during an early stage of the folding movement and it has continued in various gradations to its final stage.

Here I think is a large field for investigation : *polymetamorphism* is revealed, I venture to say, both megascopically and microscopically, constructive or destructive, or in combination, in almost every specimen of Dalradian rocks. That is the reason why non-equilibrium rocks prevail.

We may appeal to elevation of temperature, to water as a promoter of migration of molecules and of collective crystallization, or to any other theoretical explanation we please, but at any rate we have structural details, such as the spiral and S-shaped groups of inclosures in garnets, the development of the so-called chequer-albite by crushing and the eye-shaped porphyroblasts in augen-gneiss, which give evidence of *continuous crystallization* during movement. The rock mass has adapted itself to new conditions of shape and volume by mechanical, as well as by molecular, rearrangement of its particles.

It is a matter of field experience that rock deformation is accompanied by a set of characteristic minerals. For instance, albite-schists exactly like those of the Dalradian are found, in many places among the Pennide and Grisonide nappes of the Alps, in association with a drawing out of the rocks, so thorough that almost every hand specimen presents evidence of far-reaching deformation.

Many references to these subjects are found in the literature but only a few can be mentioned. Bailey has referred to the continual growth of quartz and felspar between bent and broken mica, chlorite and tourmaline. Figures and descriptions in Barrow's paper on the intrusion of muscovite-biotite-gneisses in the East Central Highlands show the decomposition of staurolite into " shimmer aggregate " (muscovite or sillimanite). From the descriptions given by Miss Elles, Barrow, and others, the different behaviour of the two micas can be observed : the biotite mostly is clearly the older member, and was sometimes already in course of destruction or transformation into chlorite during the development of fresh muscovite ; the muscovite is often in contact with and surrounding felspar which obviously has supplied material for its growth.

All rocks of suitable chemical composition show the phenomenon that we call *Deformationsverglimmerung*, i.e. the appearance of mica, especially white mica, as an indicator of deformation.

An extensive treatise would be necessary even to sketch the chemico-mineralogical processes that characterize this tectonic structure, and reappear with very close similarity in almost the same varieties of rocks in the Alps as well as in the Moravian range.

From these facts the conclusion is justified that the Dalradian rocks have not only been folded and sheared in the highest degree, but that their tectonic structure and metamorphic facies have been *impressed on them by the load and movement of a superimposed mountain mass.*

This conception finds its strongest support in the analogy with the other mountain ranges named, where the overlying block, the *traîneau écraseur*, to use Termier's expression, is still seen, and its influence on the zone of metamorphic folds is clearly demonstrable. If the Dalradian folds had developed by sliding near the surface, they would show tectonic features comparable to the Swiss Helvetian folds without any noticeable trace of metamorphism.

It is obvious that the *Creative Block*, as we may call it, in Scotland could not have come from the south-east, where the non-metamorphic folds exist; moreover the Dalradian movement is itself directed to the south-east. Only the Moinian can have played the part of the *traîneau écraseur*, and indeed, it shows the type of metamorphism that is to be expected in such a mass.

The difference between the Dalradian and the Moinian metamorphism is not a matter of degree. It concerns the very process of transformation and expresses the difference between the geological history of the two regions.

The metamorphism of the Dalradian is syntectonic; it cannot be separated from the tectonic deformation of the rocks. On the contrary, the most significant rocks of the Moinian, the quartzose granulites and the gneissose flagstones, that monotonously cover large tracts, show post-tectonic crystallization at high temperature.

I refer only to Sir John Flett's excellent descriptions, in which he pointed out the typical granoblastic and homoeoblastic structure in these rocks, the equidimensionality of the constituents, the lack of clastic or porphyritic structure, and the disappearance of all mortar structure. There is no tendency to elongation in the constituents. The parallel arrangement of biotite may have been derived from a former original parallel texture of any origin (sedimentary or tectonic, i.e. by foliation or cleavage) by mimetic crystallization (*Abbildungskristallisation*, Sander).

The contrast between the Moinian and the Dalradian is not destroyed by the fact that the Moinian itself did not behave entirely rigidly, but also suffered some deformation during its transportation, which has led to retrograde " polymetamorphism ". This may be marked in some tracts by the appearance of grains of zoisite or epidote, or of flakes of muscovite throughout even compact rocks. In

other parts it is more closely restricted to rather thick layers with rich development of mica, garnet, etc. Some of the so-called pelitic gneisses belong to the latter.

The three zones of the Scottish Caledonides constitute a *dynamic unit*. By analogy with the better preserved orogens, we can assume that the Moinian represents the " Creative Block " in the Scottish Caledonides and that it has been thrust over the Dalradian region. The breadth of the region of the Dalradian syntectonic metamorphism probably indicates the former contour of the " Creative Block ". Beyond these limits only the tangential push was operative and not the weight of the mass. The sediments were bent and folded with contraction of area, but without metamorphism.

We have, however, still to meet some apparent difficulties. It is a fact that the Moinian and its equivalents, the Eilde Flags and the Struan Flags, dip generally below the Dalradian at a rather low angle and do not overlap it, as they should, to fit the proposed explanation. But this difficulty is by no means insurmountable. The plane of contact between the Moinian and the Dalradian is to be interpreted not as a surface of sedimentation but as a tectonic unconformity.

A backward movement of the Dalradian over the Moinian has been suggested. Anderson, in regard to the Schichallion district, has put forward the hypothesis that a normal fault of large dimensions has been subjected to intense shear that came from the east or from the south and has brought all original structures, including the fault and the bedding, into approximate parallelism.

In the Alps the region of the roots at the boundary between the third and the second zone, that is between the Dinaride and the Pennide nappes, has suffered a back movement on account of the excessive and continuous push to the north during the so-called Insubrian phase (Argand).

After the compression of the orogen to its highest pitch in the Caledonides, the pressure of the continuous tangential push had more time to act, and resulted first in a greater exaggeration of the forward movement and then in more retrograde movement forming a complicated structure combining normal faulting and backward thrusting.

Therefore if we look for a backward movement comparable to that of the Lombard plain in the Alps, it will not be found in the Moine thrust, but rather in the boundary region between the Moinian and the Dalradian, the elements corresponding to the Dinarides and the Alps proper.

But what explanation have we for the Moine thrust itself ? Bailey has suggested its continuation in the Loch Skerrols thrust in Islay. There it cuts not through the Moinian but through the Dalradian, and has shifted it on to the Torridon Sandstone. It crosses obliquely the different zones of the Caledonian dynamic unit ; therefore it must be younger than the Caledonian movement, and, in my opinion, the

great thrust has no immediate relation to the Caledonian structure proper. Very likely it indicates an enormous movement far exceeding the extent of the visible breadth of superposition.

Further elucidation of this great question may be expected from the study of its supposed continuation in North America ; that is the great Champlain fault according to Bailey's suggestion (12).

Another difficulty concerns the exposures, mostly of comparatively small extent, of more highly crystalline rocks, which outcrop at numerous points below the Moinian, and are generally considered as belonging to the Lewisian. The regional geological correlations seem to me to contradict this interpretation. The Lewisian, with its cover, is obviously much older than the Caledonian movement, and it is difficult to understand how it could have preserved its original position below the Moinian, since the latter has been metamorphosed under different conditions, and was transported to the south-east in Caledonian time, as is shown by its intricate connection with the folds of the Dalradian.

Many authors have called attention to the original unconformity between the Moinian and the inliers, and to the fact that the two series appear to be separated by a surface of movement or crushing. Indeed, the interstratification of highly micaceous gneisses, mica-schists, and limestone with tremolite, and various other facts, indicate that the Moinian has been shifted over its more highly crystalline basement for an indeterminable, but probably considerable distance.

Only two explanations of these relations seem to me acceptable. Either the inliers represent a deeper facies of the Dalradian rocks which was overwhelmed by the thrust of the Moinian to the south-east during the Caledonian mountain building, or the Moinian has been moved to the south-east over an older crystalline basement together with the whole mass of the Dalradian.

Conclusion.

I venture the following statements :—

(1) The Scottish part of the Caledonides has moved as a whole and complete orogen to the south-east. In this it exactly corresponds with its much larger continuation in Scandinavia.

(2) The superposition of the Dalradian on the Moinian is to be considered as a back movement due to continuous push to the south-east. Such back movement is analogous to that which has affected the so-called Alpine roots on the boundary of the Dinarides.

(3) The Moine thrust of the North-west Highlands cuts obliquely through the Caledonian structure. It is independent of and younger than the Caledonian mountain building. By no means can it be considered a symmetrical equivalent of the south-easterly Dalradian movement in Scotland and in Scandinavia.

(4) The Caledonian orogen shows no symmetrical structure and corresponds in this respect to other large orogens, as the Alps, the Variscan range, etc.

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A Mid-Carboniferous Boulder-bed near Settle.

By E. E. L. Dixon and R. G. S. Hudson.

(PLATE V.)

Introduction and Previous Work.
Details of Exposures.
Lateral Variation in Adjacent Strata.
Interpretation and Correlation.
The Origin of the Boulder-bed.
Submarine or subaerial Landslip ?
Summary and Conclusions.

Introduction and Previous Work.

THE Carboniferous rocks east of Settle consist of :—

(2) Grassington Grit, Pendle Top Grits, and Upper Bowland Shales (Namurian [1] ; E_1).

[1] The Namurian as redefined in the *Compte Rendu, Congrès de Stratigraphie carbonifère, Heerlen*, 1927 [Liége, 1928], occurs between the Dinantian and Westphalian and roughly corresponds to the Millstone Grit of Great Britain. At that conference the subzone of *Goniatites spiralis* was provisionally taken as the junction between the Dinantian and Namurian ; in this paper the division is more definitely made in that it is drawn between the subzone of *G. spiralis* (P) and the zone of *Eumorphoceras pseudobilingue* (E_1). The definition of the upper limit of the Namurian, usually in Great Britain placed at the top of the *Reticuloceras reticulatum* Zone (R_2), does not concern us. The name "Lancastrian" is dropped.

(1) Lower Bowland Shales, P_2, Yoredale rocks and Great Scar Limestone, S_1–D_2 (Viséan).

Everywhere in the district the Namurian rests unconformably on the Viséan, [1] and the line of junction (Fig. 1) between them runs roughly eastward from Settle, past Scaleber and Stockdale Farm. South of this line the Bowland Shales and the succeeding grits form the moorlands of Scaleber and Scosthrop, drained by streams flowing south. Black Gill Beck, one of the streams, has, in a pasture known as School Share (close to Scaleber and in the angle between

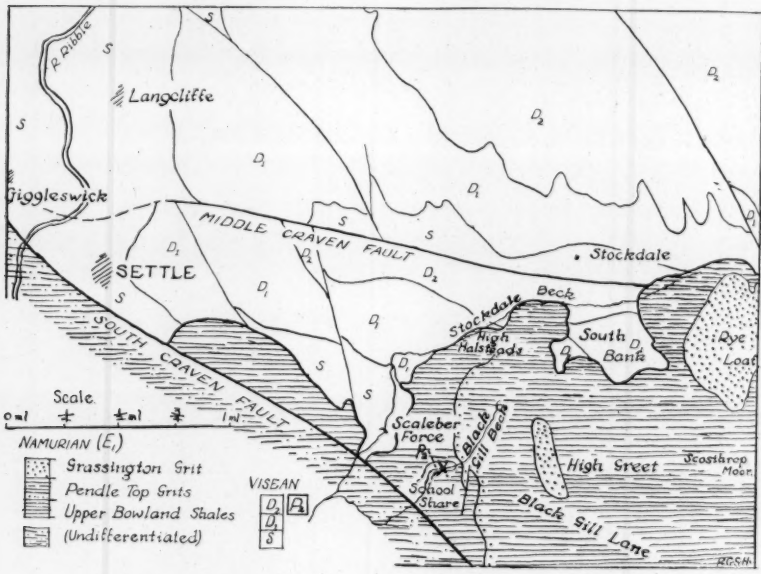

FIG. 1.—Sketch-map showing position (×) of Boulder-bed and Lower Bowland Shales at School Share. Simplified from maps by the Geol. Survey, Professor Garwood and Miss Goodyear, and R. G. S. Hudson.

Black Gill Lane and Langber Lane), cut through the Upper Bowland Shales and exposed an outcrop of the rocks which are the subject of this paper.

The most striking feature of the exposure is an assemblage of large and small masses of limestone, incorporated in shale, which has attracted attention in the past owing to several anomalies. The masses are too large to be a mere conglomerate, whilst, on the other hand, the limestones represented are of types common in the Craven Uplands to the north, and, consequently, not usually found

[1] For details of the structure of the district see R. G. S. Hudson, "The Carboniferous of the Craven Reef Belt; The Namurian Unconformity at Scaleber near Settle": *Proc. Geol. Assoc.*, xli, 1930, 290–322.

associated with Bowland Shales. Hence several explanations have been suggested. Here evidence will be adduced that the assemblage is due to a landslip or cliff-fall approximately of the age of the mid-Carboniferous unconformity.

The chief exposure, in the left bank of Black Gill Beck, about 500 yards east by south of Scaleber Force, was first mentioned by Professor Marr,[1] who considered the limestone to be a tectonic breccia. He instanced it as an example of the breaking-up produced by the folding and faulting of an isolated bed of limestone in shale, and as such he regarded it as one of the many structures produced by the great earth-movement that caused the Craven Faults.

The exposure was next considered by Professor Garwood and Miss

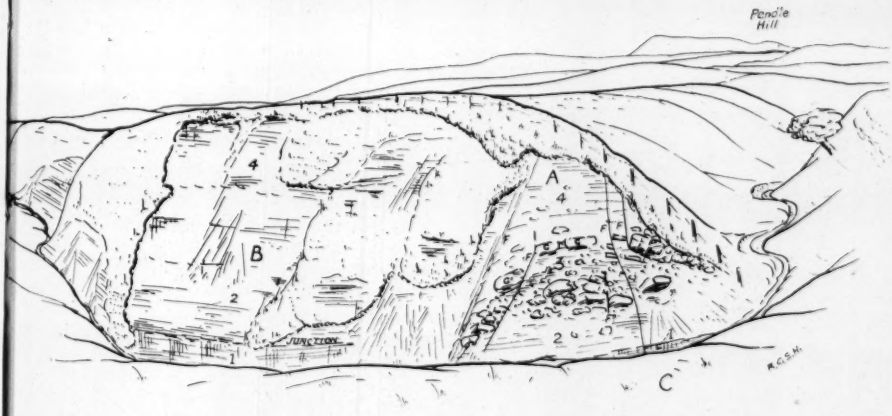

Fig. 2.—Boulder-bed and Junction of Viséan and Namurian at School Share, Black Gill Beck, Settle; looking south. A, B, C, exposures described on pp. 84–7; F, faults; G and G′, boulder(s) with *Girvanella*; 1, shales with *Goniatites* cf. *newsomi*; 2, shales with mud-plastered fragments; 3, boulder-bed; 4, shales with *E. pseudobilingue*; Grit = basement-grit of Pendle Top Grit.

Goodyear, to whom our thanks are due for pointing out its anomalous features.[2] They mention that "the limestone is much disturbed and iron-stained, and some of the blocks are partly isolated in the shale. The edges of the blocks are often rounded, and present a nodular appearance; and it is difficult to trace a definite succession in the deposit. The rock, as a whole, has a curious exotic look, resembling a fragment out of place". They

[1] "On the Limestone Knolls in the Craven District of Yorkshire and elsewhere": *Quart. Jour. Geol. Soc.*, lv, 1899, 347, fig. 12.

[2] "The Lower Carboniferous Succession in the Settle District": *Quart. Jour. Geol. Soc.*, lxxx, 1924, 230–2.

record the fauna found in the limestone and, commenting on the occurrence of *Girvanella* and *Orionastraea ensifer*, regard most of the fauna as typical of the D_2-beds of the area to the immediate north. They also record *Eumorphoceras pseudobilingue* from a neighbouring exposure of the Bowland Shales. They consider that the "deposit, apparently in the Bowland Shales, presents a problem which cannot be satisfactorily solved until the detailed succession in the rocks further south has been definitely established. Its appearance is not incompatible with the view that it represents an extension of the Yoredale Beds south of the Middle Craven Fault, over which Bowland Shales have been thrust before the Middle Craven Fault came into existence".

Details of Exposures.

Exposure A (A, Pl. V, Text-fig. 2 [1]).—This, the most important section, is about 25 yards long, and shows the following sequence :—

Boulder-bed, School Share.

		Ft.
Namurian.—4.	Dark shales with small masses of limestone ; seen to	18
3.	Boulder-bed : limestone-masses, up to 12 feet or more in length, in a shaly mudstone matrix .	16
2.	Shales with small scattered limestone-fragments .	18
	Break in sedimentation—non-sequence.	
Viséan.— 1.	Shales, closely jointed, with bullions ; seen to .	8

4. Dark shales, both papery and dicey, in places weathering spheroidally ; small masses of limestone, mostly less than 1 ft. cube, scattered sparingly throughout the lowest 12 feet and possibly extending higher. The masses are chiefly of the earthy bullion type, but some are crinoidal. Though they have yielded no fossils of diagnostic value, the crinoidal rocks at least would appear to be derived. In this section it is uncertain whether any limestone-masses above the boulder-bed (3) are authigenous, but higher up the beck bullions occur and have yielded *Eumorphoceras pseudobilingue* Bisat. At A the shales, which are seen to a thickness of 18 feet, contain poor impressions of the same fossil together with *Cravenoceras* cf. *malhamense* Bisat.

3. The largest unbroken "boulder" (G, Pl. V, Fig. 2, and Text-fig. 2) measured 12 by 5 by $3\frac{1}{2}$ feet but appeared to have been 18 feet long originally, and to have had 6 feet (G′) cut off by a small fault. The "boulders" are inclined at various angles, most of them sloping down to the east, and show no sorting other than a tendency of the largest to be in the upper part of the bed. They are generally

[1] For the photographs reproduced in Pl. V we are indebted to Mr. J. Ranson.

packed closely together, one touching the other—there are, however, comparatively large parts of the section in which the boulders are more loosely scattered. The limestones represented include sharply distinguished types—crinoidal, black and argillaceous, porcellaneous (near calcite-mudstone), and cherty rocks all being common. One block consists of several alternations of hard and soft or shaly limestone, and another is a mudstone, easily broken with the hand and full of shells of *Productus latissimus* and *P.* cf. *edelburgensis*, its junction with the enveloping shale quite distinct. The limestones include, in fact, most of the lithological types found in the Viséan to the immediate north. In general they are the dark-coloured, impure limestones of the Yoredales, rather than the light-coloured, purer rocks of the Great Scar Limestone.

Most of the masses, large or small, are angular and quite unweathered, but some have rounded edges and others are pitted. Fossils are often worn flush with the surface of the boulder. Some masses appear to have been weathered before incorporation, and in some cases, in masses freshly taken out of the shale, this apparent weathering is confined to one face. The majority are still quite unweathered. A feature of many is a closely adherent skin of black shale, partial or complete, thickening locally into hard ovoid lumps of mudstone similar to clay-galls.

The fossils show that the boulders are derived from beds in the *Dibunophyllum* Zone. In general the various boulders have distinctive fossil assemblages. Some boulders contain abundant *Productus latissimus*, others are a *Saccammina*-limestone with a small form of *Saccammina fusuliniformis* [1]; some have *Productus* cf. *giganteus*, *Lithostrotion* cf. *portlocki* and an occasional *Dibunophyllum*, whilst another type contains *Orionastraea ensifer*. One black shaly boulder has yielded abundant *Zaphrentis densa* and *Spirifer* sp. The general fauna suggests derivation from closely related horizons in the upper part of the Viséan, *i.e.*, the *Productus latissimus* and associated beds immediately below the *Orionastraea* Band in the area to the immediate north. The most interesting, as also some of the most frequent boulders, however, are those that contain abundant *Girvanella* nodules. Though these nodules suggest derivation of the boulders from the *Girvanella* Bed at the base of D_2, they differ from those found in the Craven Uplands at this horizon. They are larger and more lobate; they have a hard, black cherty limestone-matrix and have not formed around shell-fragments. They resemble much more the *Girvanella*-like nodules that occur above the *Orionastraea* Band of Fountains Fell and the area to the north and are also found close to the same band on Low South Bank (western part of South Bank, Fig. 1), a hill of Viséan limestone jutting out of the Bowland Shales less than

[1] F. Chapman has shown that "*Saccammina carteri* Brady" is synonymous with *S. fusuliniformis* (M'Coy) (*Ann. Mag. Nat. Hist.*, 1898, 215–18).

a mile to the north-east of School Share. It is probable, therefore, that those boulders containing *Girvanella* were also derived from about the level of the *Orionastraea* Band.

The matrix surrounding the boulders is rubbly shale, apparently incorporated contemporaneously with them, not deposited interstitially afterwards. It is slightly pyritous and contains no fossils.

The thickness of the boulder-bed is 16 feet near the fault at the east end of the section, but falls away to 10 feet westward. Within the limits of the section the base appears to have been fairly even, but it has been somewhat disturbed by small faults (see Fig. 2).

2. Dark shales with occasional goniatite-bullions and scattered angular fragments, chiefly small, of limestone and shale. The limestone-fragments are chiefly argillaceous, but some are fairly pure, with crinoids or brachiopods. In some cases (see Pl. V, Fig. 2, inset) their derived nature is obvious from the tilt of the bedding of a fragment, in contrast with the horizontal enclosing shale. A feature is that most of the fragments escape notice at the surface, since usually each is completely enclosed by a covering of soft mudstone. This covering, which like some of the fragments, has weathered considerably and is now iron-stained, is about 1–2 inches thick and, having an even outer surface, forms a smooth mass with rounded outline, in sharp distinction from the irregular limestone-fragment inside. The mudstone-covering is also very distinct from the surrounding shale. It is not a zone of weathering of the limestone-fragments, as the latter are sharply marked from the outer mudstone, and some bullions in the same bed show no outer zone. The surrounding shale contains small lamellibranchs (*Posidoniella* ?), apparently indigenous. The fragments were traced for 18 feet below the boulder-bed, *i.e.* to about beck-level. Here, sometimes submerged, is the junction with the underlying shales (1), the nature of which is another of the features of the section.

This junction is marked by a few inches of mudstone of abnormal texture, like that of weathered shale that has lost its fissile character and is little more than a " mush " of mudstone. The mudstone varies in thickness and is sharply separable from the shale below, into which it cuts down abruptly in places. It grades, however, into the shale (2) above.

1. Dark shales with a few bullions some containing *Goniatites newsomi* Bisat and *Sagittoceras* cf. *meslerianum* Bisat. The shales are fissile, and their jointing is so close as to resemble cleavage or the " cleat " of coal. They contrast markedly, therefore, with the non-jointed shales of bed 2, which, further, are more rubbly and less thinly-bedded. The lower shales (1) are seen to a thickness of 8 feet.

Other Exposures in School Share.—These show at once that the boulder-bed, in the striking development described above,

is local but that its horizon is persistent. Westward of A the bed was traced for 12 yards by digging in the grassy bank beyond the posts seen in Text-fig. 2. Here it maintained the same gentle inclination observable at A, but was devoid of large blocks and was apparently thin.

At C, north of the beck, the horizon was followed only with difficulty. Owing to the slight dip it is higher above the stream. It is marked by small masses of earthy limestone, some with crinoids; only one fragment of pure limestone was found.

Eastward of A no large boulders occur beyond the fault, shown on Pl. V and Fig. 2, which appears to throw the bed against totally dissimilar shale. The fault is, however, small, its throw, measured by the displacement of the junction-layer between beds 1 and 2, being about 15 feet. Immediately east of the fault the bank is grass-covered, but about 10 yards beyond there is a good exposure (B, Text-fig. 2). Beds 1 and 2 and the junction-layer (J, Pl. V, Fig. 2) are well seen, but the boulder-bed is indicated merely by a few small fragments of limestone in shale about 30 feet above the junction-layer. No limestone-fragments are found in bed 4 which, as previously mentioned, contains bullions with *E. pseudobilingue*.

Cracoe.—Although the boulder-bed is local, the peculiar conditions of its formation extended into the Cracoe area, for there, at one exposure, blocks of limestone, much smaller than at School Share but showing some variety (some containing *Productus latissimus*, others abundant crinoid-ossicles), mark the base of the Upper Bowland Shales and rest on shales of P_2 age.[1]

Lateral Variation in Adjacent Strata.

The boulder-bed then may be presumed to be of *E. pseudobilingue* age, that is, it is part of the Upper Bowland Shales. On Scosthrop Moor, to the east, the Bowland Shales are followed by the Pendle Top Grits, a series of shales with subordinate grits; and they, in turn, are succeeded by the Grassington Grit, thick, coarse, pebbly grits exposed on Rye Loaf Hill.[2] Several features about these two grit-series bear on the origin of the boulder-bed. The Pendle Top Grits, although well developed in the upper part of Black Gill Beck, thin out to the north towards High Halsteads and Low South Bank, and the entire sequence becomes a succession of shales. Furthermore, owing to overlap the basement-beds of the Namurian change rapidly in horizon. At School Share they are Upper Bowland Shales, and the base is about 70 feet below the Pendle Top Grits

[1] K. M. Booker and R. G. S. Hudson, "The Carboniferous Sequence of the Craven Lowlands South of the Reef Limestones of Cracoe": *Proc. Yorks. Geol. Soc.*, xx, 1926, 429–30.

[2] R. G. S. Hudson, "The Carboniferous of the Craven Reef Belt: The Namurian Unconformity at Scaleber, near Settle": *op. cit.*, 306–8.

(exposed near B); north-eastward the basement-beds rise in horizon till at High South Bank only about 30 feet of shale separates the Grassington Grit of Rye Loaf Hill from the Viséan. The overlap, in fact, is so great and so rapid as to demonstrate deposition against a considerable slope rising northward. At the time when the Upper Bowland Shales were being deposited at School Share, Viséan rocks immediately to the north-east either were above water or, if submerged, were above the zone of sedimentation.

Interpretation and Correlation.

The chief facts to be noticed are as follows:—The limestone-fragments persist beyond the exposure (A) of boulders and occur also in the shales (2 and 4) immediately below and above. The faults seen at A are slight and incidental; they appear to have had nothing to do with the presence of the boulders in the shales. Especially noteworthy are the upper shales (4) with limestone-fragments, as these have most clearly not been disturbed since deposition. In the boulder-bed the boulders and smaller material are unsheared and are not phacoids. They are mostly angular; some, apparently, were partly weathered before incorporation. The adherent films of shale, previously mentioned, suggest that some of the boulders were pressed forcibly into the black mud, whilst the coating of mudstone around the smaller fragments in bed 2 seems to point to these fragments having rolled on a muddy surface and, in doing so, plastered themselves liberally with mud. The limestones come from various beds, all of which, so far as known, belong to the Upper Viséan. The shales (2, 3, and 4) that contain boulders and limestone-fragments are separated from those (1) below by a plane, apparently of erosion and weathering, but the evidence is not sufficiently clear to demonstrate an interval of subaerial exposure.

Hence it may be concluded that the boulder-bed is not autoclastic or overthrust, but that its boulders, however transported, mark aninterruption in placid shale-deposition, due to abnormal conditions consequent, presumably, on some slightly earlier earth-movement.

Confirmation of this earth-movement is afforded by the goniatites. Bed 1 contains *Goniatites newsomi* and *Sagittoceras* cf. *meslerianum*,[1] species found in the Lower Bowland Shales and therefore of late Viséan (P_2) age, whilst bed 4 with *Eumorphoceras pseudobilingue* and *Cravenoceras* cf. *malhamense* evidently belongs to the Upper Bowland Shales, of early Namurian (E_1) age. That is, the top of bed 1 divides Namurian from Viséan and, therefore, is the horizon

[1] The authors thank Mr. W. S. Bisat for identifying all the goniatites found at School Share and Mr. W. B. R. King for indicating the bullion containing these particular forms.

at which a marked unconformity has been shown to exist close by.[1] This mid-Carboniferous unconformity extends also through many parts of Great Britain.[2]

A comparison with other regions throws further light on the nature of the break at School Share. The most complete sequence known of the goniatite-bands at the junction of the Viséan and Namurian in N. England is as follows [3]:—

	Zone.	Goniatite-Band.
Namurian	Base of *E. pseudobilingue* Zone (E_1)	*Cravenoceras leion.*
Viséan	*Goniatites spiralis* Zone (P_2)	*Sagittoceras coronula.* *Goniatites subcircularis.* *G. newsomi* and *S. meslerianum.* *G. splendens.* *G. granosum.*

It is evident, therefore, that the shales below the break at School Share lie almost at the top of the Viséan. At Dinckley, near Clitheroe, where the *G. spiralis* Zone is apparently complete, the *G. newsomi* band is only 14 feet [4] below the *S. coronula* band, the top band of P_2, and since that zone thins northward thence to the Craven area, there could have been little erosion (or non-deposition) of the Viséan at School Share.

The *E. pseudobilingue* Zone (Upper Bowland Shales), on the other hand, maintains a fairly constant thickness of about 350 feet. At the base and near the top respectively are bands with *C. leion* and *C. malhamense*. The Upper Bowland Shales of School Share are only about 70 feet thick and contain *C.* cf. *malhamense*. The horizon of the boulder-bed appears, therefore, to be towards the top of the zone and the greater part of the latter to have been overlapped.

The Origin of the Boulder-bed.—The size, angularity, composition, general absence of weathering and various other features point unmistakably to a local origin—the deposit itself from its abrupt appearance is evidently of local distribution. The separation from the parent rock and burial of the limestone-masses must have been rapid and forcible, and there was little, if any, intervening subaerial exposure. There seems no likely way by which the blocks could have reached their present position except by detach-

[1] R. G. S. Hudson, *op. cit.*, 308–12.

[2] See E. E. L. Dixon in "The Geology of the Whitehaven District": *Proc. Geol. Assoc.*, xxxvi, 1925, 53.

[3] W. S. Bisat, GEOL. MAG., LXV, 1928, 43; and *Compte Rendu, Congrès de Stratigraphie Carbonifère, Heerlen*, 1927 [Liége, 1928], 125.

[4] Communicated by Mr. E. W. J. Moore.

ment from a cliff or scarp by a land-slip or cliff fall and subsequent slipping down a mud-slope into the muds of the Upper Bowland Shales.

The boulder-bed, therefore, is a subaqueous talus-breccia of Reynolds' classification.[1]

The nature of the limestone-masses and the rapid north-eastward rise of the pre-Bowland Shale floor suggests a northerly origin for the masses, despite their non-appearance in the northern bank of the beck; the probability of an extension of the northern facies of the Upper Viséan under the Bowland Shales of the immediate south is slight.

The northward rise of the pre-Namurian floor is shown not only by the rapid overlap at the base of the Namurian, previously mentioned, but also by the varying height of that base (Text-fig. 1). The Namurian shales have little or no dip—their slight and rather erratic southward dip may be an original dip of deposition, yet their junction with the underlying Viséan limestones is at 1,300 feet O.D. south of Crutching Close, near Stockdale; 1,550 feet at High South Bank; 1,125 feet near Low Barn; while at the boulder-bed in Black Gill Beck the junction with the Viséan shales is at about 1,075 feet. All these points lie south of the Middle Craven Fault. While the fall in height, about 500 feet in less than a mile, may be partly due to post-Namurian faulting, there seems little doubt that it is, in the main, a measure of the uneven surface against which the Namurian has been deposited. From such an irregular, scarped surface the boulders might well be derived.

Neither boulders nor smaller limestone-fragments are known anywhere from P_2-shales, and the time-interval between the latter and the boulder-bed is not great. The production, within that interval, of a large cliff of older rocks close to this area of almost continuous deposition calls, therefore, for some such "rush" method as that of an earthquake. The emplacement of the deposit in the Craven Fault-system, a deep-seated and long-enduring line of crustal weakness, suggests immediately that Tiddeman was right in claiming that movement occurred along this line in Carboniferous times. It has been suggested[2] that the movement that resulted in the overstep of the Viséan from D_2 to S_1 was partly of the nature of faulting, associated with the Craven Faults, and that there were at least two periods of the faulting, the earlier within late Viséan time and the later at the close of the Viséan. It was the later movement that resulted in the break after the deposition of P_2 at School Share, and presumably it raised the scarp from which the overlying boulders were derived.

Submarine or Subaerial Landslip ?—Since coming to the conclusion outlined above we have read the remarkably interesting paper by

[1] "Breccias," GEOL. MAG., LXV, 1928, 100.
[2] R. G. S. Hudson, *op. cit.*, 315–17.

Professors Bailey, Collet and Field [1] on the limestone conglomerates in the Lower Palaeozoic near Quebec. It is there pointed out that similar controversial conglomerates occur also in the Wildflysch of the Alps and in the Kimmeridgian of Brora. All occur as anomalous deposits, generally including blocks of gargantuan size in penecontemporaneous shales and near important faults. Without discussing the application of their theory to the extra-American examples we need only state that the authors explain the blocks as the result of intermittent slips from developing submarine fault-scarps. The exposed blocks at School Share are small by comparison with some of those mentioned by the authors, but on the whole the circumstances are remarkably parallel. Their explanation goes further than ours, in suggesting earthquakes as the cause of the slips and the site being submarine at the time. Earthquakes may well have caused the School Share slip, and it may be too that the fault-scarp was essentially submarine. The movements in and at the close of late Viséan time certainly did result elsewhere in pre-Namurian erosion, which, though greatest along fault-lines, was widespread and presumably subaerial. At School Share, however, the main result of the movement at the end of P_2 was not erosion of the Viséan but non-deposition of the earliest Namurian.

Summary and Conclusions.

(1) The blocks of limestone in the Bowland Shales of School Share include a variety of rock-types of northern (Yoredale) facies and come from several beds near the *Orionastraea* Band of the Upper Viséan.

(2) They are a local accumulation at the local base of the Namurian (Upper Bowland Shales; zone of *Eumorphoceras pseudobilingue*, E_1) and rest, with evidence of some slight erosion, on one of the highest horizons of the Viséan (Lower Bowland Shales; zone of *Goniatites spiralis*, P_2). Their horizon, therefore, is that of the mid-Carboniferous unconformity of Settle and elsewhere.

(3) They mark a comparatively small faunal hiatus (between the *newsomi-meslerianum* level immediately below and the *C. malhamense* level above).

(4) Their separation from the parent rocks and their assemblage are not due to tectonic causes. On the other hand, their great size points to some unusual form of transport.

(5) As they occur in a shale series near the Craven Faults they may legitimately be explained as the result of land-slips down a muddy slope from a limestone cliff, probably a fault-scarp raised by the mid-Carboniferous earth-movement.

[1] "Palaeozoic Submarine Landslips near Quebec City": *Jour. Geol.*, xxxvi, 1928, 577–614.

(6) The circumstances recall those attending the Lower Palaeozoic conglomerates of Quebec. A recent explanation ascribes these to landslips caused by earthquakes from submarine fault-scarps. The School Share landslip may well have been caused by earthquakes, and the scarp from which the blocks were derived may have been essentially submarine.

EXPLANATION OF PLATE V.

FIG.

1.—A and B are exposures described on pp. 84–7, the positions of the beds and the faults being shown on Text-fig. 2. G is a 12 ft. block of *Girvanella* limestone and G′ its probable continuation beyond a small fault (p. 84). J is the junction of the Viséan and Namurian at B (p. 87).

2.—Near view of part of exposure A, GG and G′ being the *Girvanella* limestone. Inset is a near view, below x, of a tilted isolated block of crinoidal limestone in shales of bed 2, its outline strengthened. The lower right edge of the pale area seen in it is a bedding-plane.

REVIEWS.

LIVING AFRICA: a Geologist's Wanderings through the Rift Valleys. By BAILEY WILLIS. Pp. xv + 320, with plates and maps. London: McGraw-Hill Publishing Co., 1930. Price 20*s*.

THIS is a difficult book to review, owing to its many-sidedness. It comprises a charmingly written narrative of travel, with constant touches of humour, generous appreciation of British methods of administration in Central and East Africa and scathing criticism of the inadequacy of the British "small car" in the same and similar regions. Underlying all this is much acute geological observation and inference, as would be expected from the original mind of Professor Bailey Willis. In the introduction, which is largely geological, we get a delightful glimpse of Eduard Suess in his old age in the course of a discussion of subsidence as a geological factor. The keynote of the whole discussion throughout the book is that the author does not believe in subsidence in the Suessian sense: he does not even believe in isostasy, nor, it need hardly be said, in continental drift. He does not believe in the foundering of Gondwanaland, using this term in the sense of a continent formerly occupying the site of the present Indian Ocean. In this "drifters" will doubtless agree with him. These last, however, think that Gondwanaland still exists, only in pieces.

The author's main object was to study the Rift Valley system and its associated volcanoes. This he did pretty thoroughly, and it is stated that the results are to appear in a monograph published by the Carnegie Institution. This will be eagerly awaited. But we

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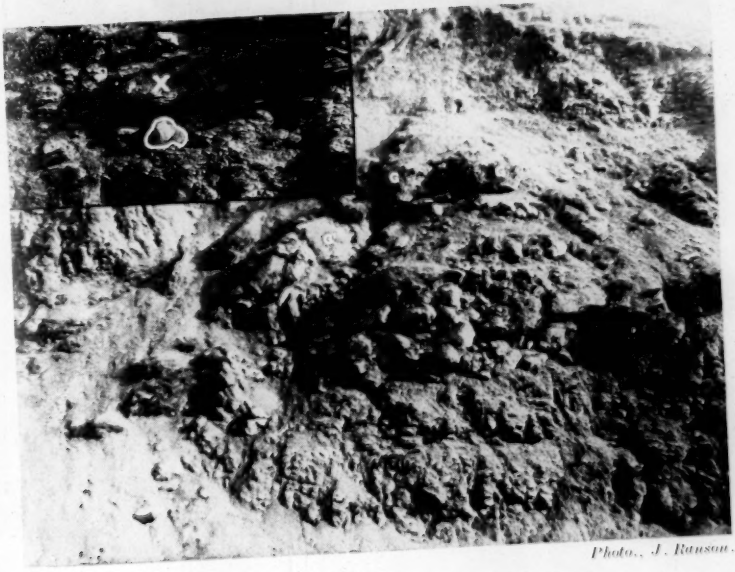

Photo., J. Ranson.

Boulder-bed at School Share, Settle.

(*To face p.* 92.

are here given a forecast of the main conclusions. In the first place, the Rift Valleys are attributed to uplift and outward pressure from a more or less circular block of country around Victoria Nyanza. Many of the supposed fault-scarps are considered not to be of this nature, and it is apparently only in the eastern rift, specially studied long ago by Gregory, that the author admits the existence of tension in the usually accepted sense. In the west he found evidence of compression and even of overthrusting. The full technical discussion of all this in the promised monograph will be of the greatest interest. The theory suggested to explain this uplift with its accompanying pressure may perhaps tentatively be summed up as "metamorphic adjustment". That is to say, certain blocks of the crust are supposed to become highly heated below, thereby expanding and recrystallizing, thus exerting an outward and upward push. This is applied not only to the Rift Valley system, but also to the ocean floors, as a cause of continental uplift in general. This idea will require a lot of consideration in the light of the physical chemistry of minerals. And no reason is given for the necessary rise of temperature, though perhaps Professor Joly's theory will come in usefully here. But it is impossible here to give any idea of the numerous points raised: the book should be read and pondered over. It will well repay the time spent, though some readers will perhaps disagree violently with certain of the theoretical conclusions.

The frontispiece is a beautiful coloured sketch of the Victoria Falls, and the small tail-pieces at the end of each chapter are delightful.

R. H. R.

Scandinavian Trinucleidae, with special reference to Norwegian species and varieties. By Leif Störmer. *Skrift. Norske Vidensk.-Akad.* Oslo. I, Mat.-Nat. Klasse, No. 4, 1930. Pp. 111; pls. xiv; text-figures 47.

THE Trinucleidae found in the Middle and Upper Ordovician of Norway have not been described since the work of Angelin (1851–4). In addition to a systematic account of the Scandinavian forms the author deals with their morphology, ontogeny, phylogeny, distribution, and mode of life. An interesting point is the evidence brought forward to show that the median tubercle on the glabella is a true median eye consisting of four or five ocelli.

CORRESPONDENCE.

THE APPLICATION OF MECHANICAL ANALYSIS TO GEOLOGICAL MAPPING.

SIR,—Volume xl (1929) of the *Proceedings of the Geologists' Association* contains a paper on the geology of the country around Reigate. This describes some of the results of an intensive study of a relatively small area, in which the Lower Greensand rocks consist almost entirely of sands, silts and clays and are devoid of fossils. In these circumstances it was found desirable to supplement observations of ordinary lithological characters by a free use of mechanical analysis. As the work proceeded it was found that there was no great difficulty in distinguishing the two larger divisions, viz. the Folkestone Beds and the Hythe Beds, from each other in the field, since it was discovered that the glauconitic silts and sands which are regarded as the representatives of the Sandgate Beds in this district, extend right across the area surveyed.

It was, however, desired to find out whether there were any characteristic differences between successive strata on a smaller scale, and if such existed to sub-divide the main divisions, and further to determine to what extent these facies horizons persisted along the outcrops or in what way they varied or developed laterally. The results obtained appeared to be sufficiently interesting to be recorded, and they were set out in the paper in the opening paragraphs of the section on Stratigraphy and in the sub-section on the Application of Mechanical Analysis.

Since the Reigate paper was published, the Officers of the Geological Survey have finished a survey of the whole of the 1 in. sheet of the Ordnance Map which covers the small area dealt with in the paper. Section VII of Part II of the *Summary of Progress of the Geological Survey for* 1929, under the title " The Application of Mechanical Analysis to Geological Mapping ", describes what the authors have accomplished by the use of this method in the districts lying east and west of the Reigate area. The authors state that their results were such as to yield no indication of the horizon of the samples, and that they were negative as regards evidence for use in geological mapping.

The authors also include in this section a number of quotations from the Reigate paper, which set forth the main conclusions arrived at from the work done in that district to which the use of mechanical analysis contributed, and, on the ground of the work done by themselves in the adjoining areas, they dissociate themselves from such conclusions. Moreover, the authors commit themselves to such broad negative propositions as that " it is unsafe to base any

stratigraphical deductions on evidence gained by the application of the methods of mechanical analysis to the Cretaceous sediments ".

In view of these aspects of the authors' publication it seems desirable that there should be no delay in giving expression to some of the criticisms for which they call. It is not, however, possible to do this fully in the limited space of a letter. One must be content here to call attention in the briefest manner to a few of the points which call for comment.

For example, the authors assume (1) that the Reigate paper deals with the Lower Greensand, and even the Lower Cretaceous sediments in general, and prescribes stratigraphical divisions of general application irrespective of their extent or location: and (2) that mechanical analysis was used primarily for the purpose of discriminating between the larger divisions of the Lower Greensand, for example, the Folkestone Beds and the Hythe Beds. With regard to the first assumption, it is surprising that it should be necessary to point out that the Reigate paper deals, in fact, with a restricted area, and that the results obtained from a very large number of analyses are valid for that area. Obviously, from the nature of the case, the bearing of these results on adjoining or other areas can go no further than to suggest that a similarly thorough use of mechanical analysis might possibly yield equally interesting results. As to the second assumption, it is only necessary to read the first page of the section on Stratigraphy in the Reigate paper, especially the first four sub-paragraphs, which the authors themselves quote on p. 75 of the *Summary of Progress*, to perceive that the purpose in view and the results arrived at had reference primarily to the sub-division of the major divisions: the distinctions drawn later in the paper between the major divisions as wholes emerged from a comparative study of the whole series of curves.

The principal criticism of Section VII of the *Summary of Progress* relates, therefore, to propositions which were not stated in the Reigate paper, and so calls for no reply further than pointing out the authors' erroneous assumptions.

With regard to the authors' own work, it will suffice for the present to draw attention to the fact that the sweeping negative conclusions arrived at were based on a total of twenty-four samples collected from many square miles of Lower Greensand outcrops east and west of Reigate.

A fuller treatment of these points and of others raised in the *Summary of Progress* awaits an opportunity for further publication.

F. Gossling.